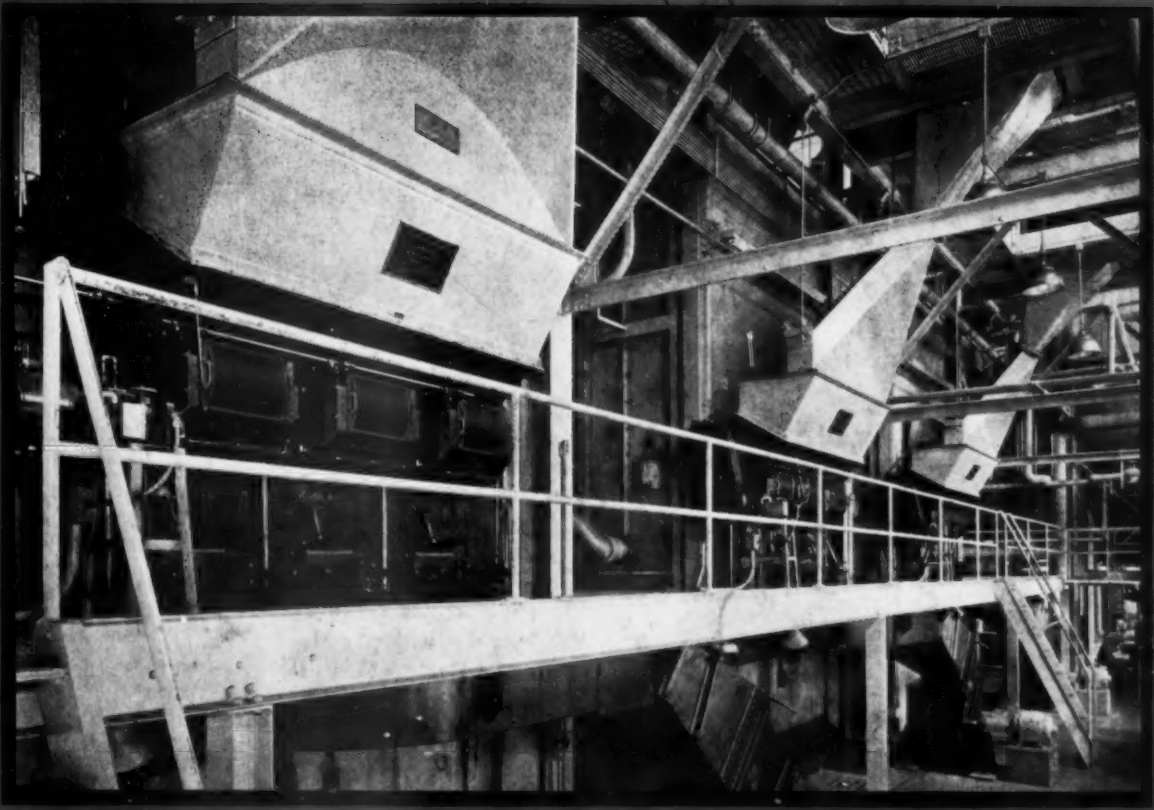
COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

July, 1944



Spreader stokers firing boilers in a defense plant

Mobile Power Plants for Service Abroad

X-Ray Diffraction—A New Industrial Research and Control Technique

Fuel Problems Discussed by A.S.M.E.

COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

VOLUME SIXTEEN NUMBER ONE

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FOR JULY 1944

FEATURE ARTICLES

EDITORIALS

DEPARTMENTS

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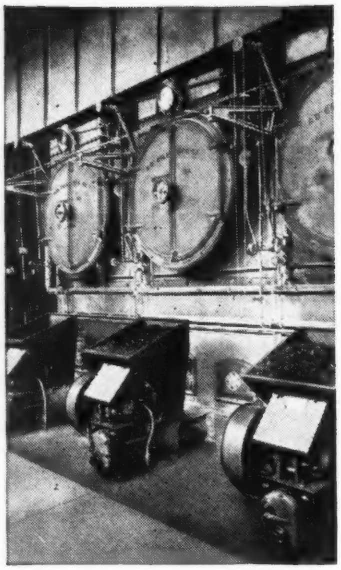
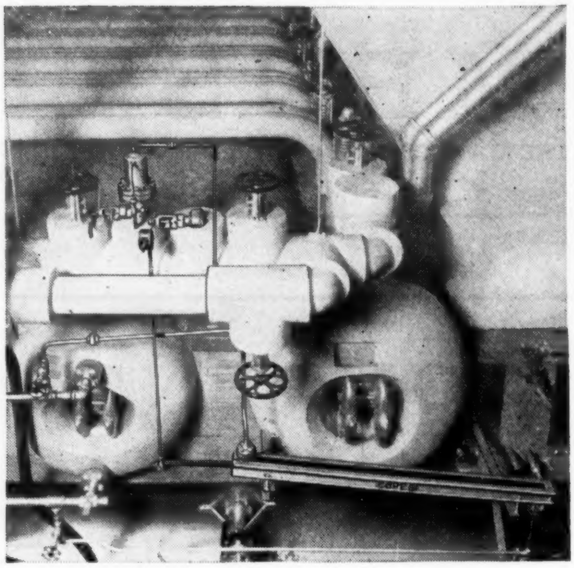
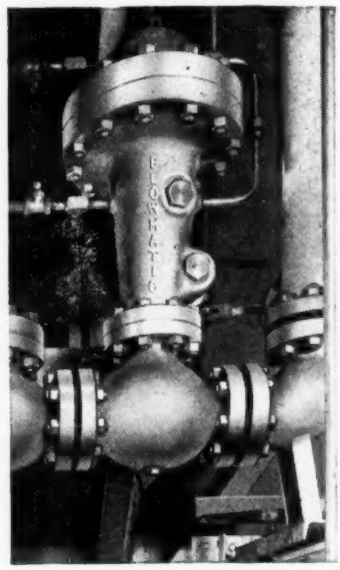


Atlanta Ice & Bottling Co., Atlanta, Georgia. 3 Copes Type OT Regulators installed on HRT Boilers operating at 100 pounds pressure.



Industrial Plant. One of two feed lines to 650-pound pressure C-E Boiler handling a peak of 150,000 pounds per hour, controlled by a Copes Type BI Regulator and Type 3-S-2 Differential Valve.



Eddy Paper Corp., White Pigeon, Mich. Direct-operated Copes Flowmatic Regulator Valve on 550-pound Badenhausen Boiler.

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EDITORIAL

Marine Demands for Oil

Writing in the current issue of *Public Utilities Fortnightly*, Edward Falk, Director of the Office of War Utilities, mentions incidentally that one of our latest type of battleships requires approximately 200,000 horsepower of turbine capacity, a large aircraft carrier about 180,000 horsepower, a light cruiser 100,000 horsepower, and that the aggregate capacity of main propulsion units for all types of vessels in our Navy is approximately equal to the total installed generating capacity of all electric generating stations in the United States.

These are amazing figures, but if there be added the ten to twelve million horsepower in cargo vessels constructed under the Maritime Commission program, one gains some conception of the marine demands for oil over the last two or three years. And these demands will continue to increase as more vessels are built.

Added to this are the tremendous aviation requirements and other demands on the fighting fronts, for both ourselves and our allies. Secretary Ickes has stated that at least a third of the country's oil production for this year would be required by our fighting forces and, according to an official of one of our largest oil companies, nearly two-thirds of the tonnage of supplies shipped overseas represents petroleum or petroleum products.

It is not surprising, therefore, that we must look to coal, rather than to oil, as a source of stationary power and heat—at least until hostilities cease, and, perhaps, for a long time thereafter owing to depleted reserves. The availability of oil in the future depends on factors now unpredictable; hence cannot be counted upon in present planning. It is most important that we make our available supply of coal stretch as far as possible by paying strict attention to efficient operation and elimination of waste.

Electric Boilers

Electric boilers have long found use abroad in those countries where water power is abundant and fuel scarce. They have also been employed rather widely in Canada and, to a limited extent, in some sections of the Northwest. For the last few years, however, they have received scant attention either in Canada or this country because of restrictions on electric energy for war production.

Looking ahead, however, to the post-war period, the situation may be different. The capacities of Federal hydro projects, particularly in the Northwest, have been greatly amplified to provide large blocks of power for chemical and metallurgical processes that require vast quantities of electric energy. In some instances these demands have already begun to taper off as reserves have been built up, and the end of the war will release this power to meet peace-time manufacture. It probably will be a long time, however, before such demand in these areas can fully absorb the available capacity. Meanwhile it is to be assumed that the governmental agencies which administer these projects will make every effort to find markets for the available power and will offer incentive rates. Electric boilers for those industries employing process steam may afford one outlet.

Viewed locally, the availability of hog fuel, so widely used in some sections of the Northwest, will be a competitive factor. In some localities this is still abundant, whereas in others it is dwindling. Moreover, lower fixed charges, space saving and the lesser operating force are points in favor of the electric boiler, especially in these days of high labor cost. Their use may also be influenced by the present nation-wide movement toward fuel conservation which is likely to endure for some time.

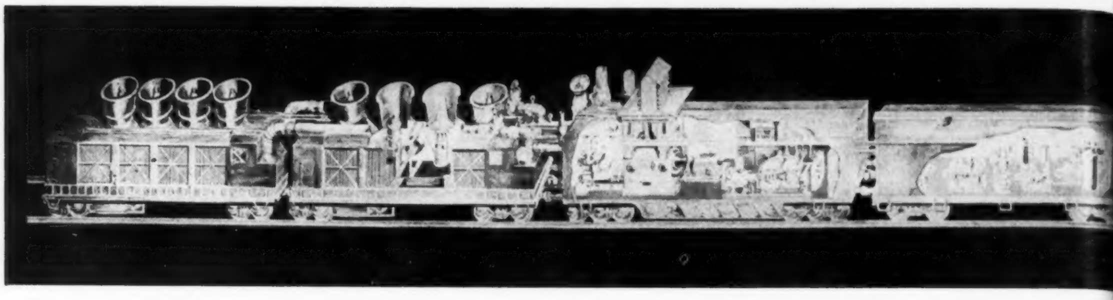
Electric boilers are now under construction for capacities ranging from 15,000 to about 150,000 pounds of steam per hour and it is assumed that, as demand dictates, they will be subject to more intensive development, as to capacity and pressure, than has been the case in the past. They can be regarded as competitive with the steam boiler only under such conditions as are particularly favorable to their use, but these instances would appear sufficient to prophesy a renewed interest in this type.

Statistical Data to Be Resumed

The U. S. Department of Commerce announces that it is preparing to re-establish the flow of statistical information to business and industry as soon as requirements of military security will permit. Such information will be an important aid to reconversion in many lines. In fact, much of the preparatory work is now under way and suggestions are being solicited as to items that may prove most helpful.

It will be recalled that the Biennial Censuses of Manufacture scheduled for 1941 and 1943 were suspended by Executive order, under the Second War Power Act; hence, the most recent census information now attainable relates to 1939. That is now practically useless, due to the impact of war. Therefore, the Department of Commerce is planning to conduct a Census of Manufacture for 1946.

Up-to-date figures are currently published by the Federal Power Commission on the central-station industry, but in the past, data on private power plants, as contained in the Census of Manufacture, have left much to be desired. As war production has left its imprint on privately generated power, not only as to the installation of new equipment but also the use of many old units, it is certain that manufacturers of power equipment would welcome statistical information that will give a true picture of that situation.



MOBILE POWER PLANTS

A review of the 5000-kw and the 1000-kw coal-burning steam-power plants mounted on railway cars, or so-called "Power Trains" and the 500-kw semi-portable "Package Type" steam plants, all designed to supply essential services in war-devastated regions.

AERIAL bombing, bombardment within combat zones, and demolition by retreating forces have been responsible for widespread destruction of power facilities and given rise to a need for emergency power plants to supply both military requirements and primary civilian needs in occupied areas; also to provide initial power in the rehabilitation of devastated areas. To meet this pressing demand three types of plants have been designed and are being built in large numbers in this country for service abroad. These are the mobile steam power plants mounted on railway cars and designated as "Power Trains"; the "Package Type" of steam power plant, standardized in the 500-kw size and designed for convenient transportation or relocation; and the small portable gasoline- or oil-driven sets similar to those often employed in construction work.

The "Power Trains" are being built in capacities of 5000, 3000* and 1000 kw to meet various requirements and all will burn coal. A brief review of these was contained in the June issue of COMBUSTION in reporting a meeting of the Metropolitan Section, A.S.M.E., but it is now possible to give a more detailed description of the 5000-kw and 1000-kw trains, as well as information on the "Package Type" power plants. This was brought out in papers at a session of the Semi-Annual Meeting of the A.S.M.E. at Pittsburgh on June 21.

C. M. Laffoon of Westinghouse Electric & Manufacturing Company, the general contractor for the 5000- and half of the 1000-kw power trains, discussed their various features and was followed by **Otto de Lorenzi** of Combustion Engineering Company, which designed and built the boilers for the 5000-kw trains. **F. G. Ely** of Babcock & Wilcox Company discussed the boiler equipment of the 1000-kw trains. **Lester E. F. Wahrenburg,** as joint author of a paper with **H. H. Van Kennen,** described the "Package Type" plants as designed by the Peter Loftus organization of Pittsburgh.

As stated by Mr. Laffoon, there are now in various stages of construction or completed by his company, ten 5000-kw and twenty-four 1000-kw portable, self-contained steam-electric power plants, assembled in specially designed railway cars which, with suitable trucks, can be transported over most American and some foreign railways. They can be operated when located on railway sidings provided with the necessary supplementary foundation supports.

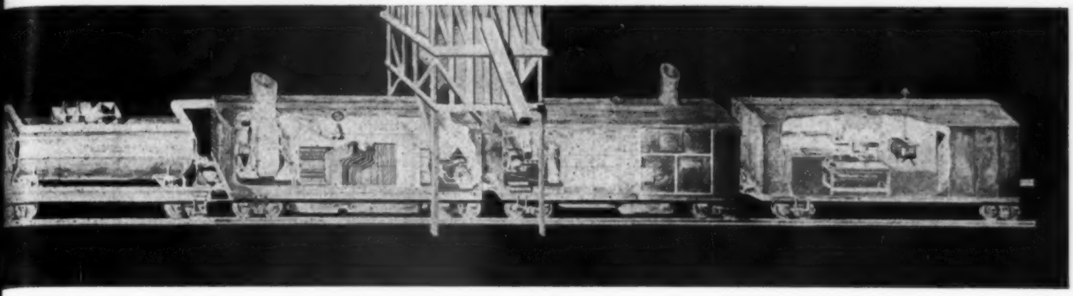
The primary objective was to obtain the maximum output per unit of materials and the meeting of operating conditions imposed; performance efficiency, while not neglected, was of secondary importance. The design was restricted by railroad clearances, axle loads, low-grade fuel of approximately 7300 Btu, 22 per cent ash and 24 per cent moisture; ambient temperature range of -40 F to $+95$ F; limited water supply for makeup and cooling purposes, and ability to start without an external source of power. Furthermore, mechanical problems involved strength to withstand vibration with the cars moving at freight-train speed, high impact forces due to sudden starts and stops, and twisting forces caused by such contingencies as car derailment.

5000-Kw Power Train

The requirement that the power plant operate with a minimum loss of water made it necessary to use a closed steam cycle and air-cooled condensers. Space and weight limitations, and reliability were important factors in determining the steam conditions for the 5000-kw, 3000-rpm prime mover at 600 psi gage and 750 F at the throttle, and exhausting at 2 psi gage. Under these steam conditions the turbine-generator will require 80,000 lb of steam per hour to produce a gross generator output of 5000 kw. Space limitations, steam production requirements, and the low-grade fuel for the furnaces fixed the type and number of boilers, superheaters, economizers and other steam-generating auxiliaries.

Eight railway cars of the freight type and approximately 50 ft long are required to house and support the main and auxiliary power-plant equipment. All cars have double walls for all exposed surfaces with thermal

* Forty 3000-kw trains, each consisting of seven or eight cars, are being furnished by General Electric Company. The boilers are of the fire-tube locomotive type, designed to operate at 300 psi. They are not included in this description.



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insulation placed in the interwall space. The designation and arrangement of the cars are as follows:

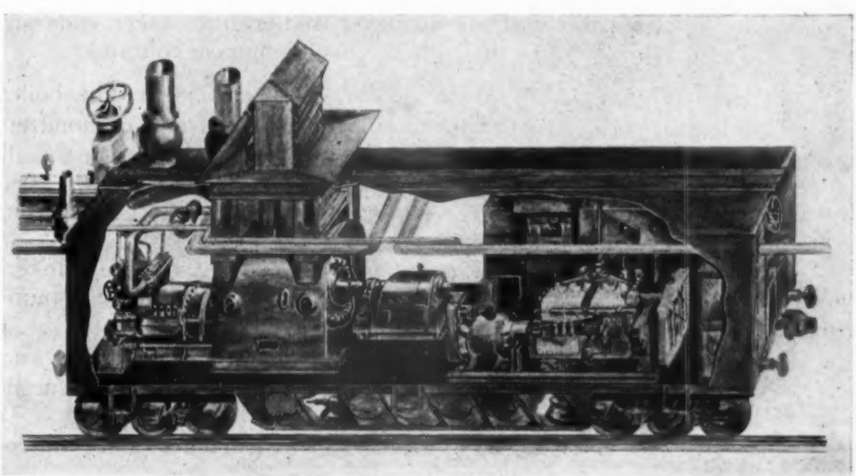
Cars No. 1 and No. 2 for the main steam condensers.
Car No. 3 for the main turbine-generator unit and switchboard.
Car No. 4 for the air compressors and the boiler feed pump.
Car No. 5 for the boiler feedwater.
Cars No. 6 and No. 7 for the main steam-generating equipment.
Car No. 9 for work shop and living quarters of the operating crew.

Each train will be supplied with the essential coal- and ash-handling equipment required to operate the power plant.

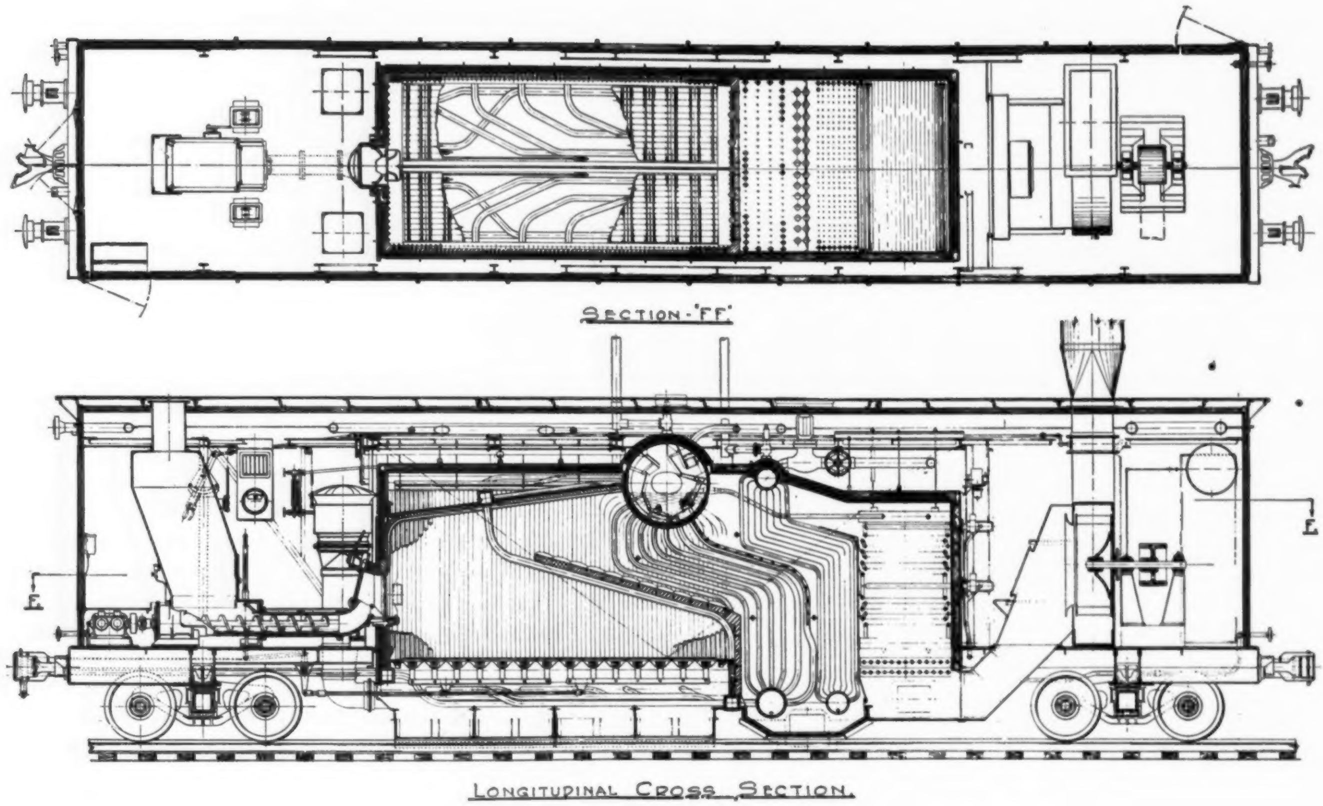
AIR-COOLED CONDENSERS: The main steam condensers are novel in that air is used as the cooling medium. They are designed to condense the exhaust from the 5000-kw turbine at a maximum back pressure of 2 psi gage when cooled by air at temperatures from -40 F to $+95$ F. It is imperative that steam be supplied to all the cooling surface; otherwise under extremely low ambient conditions, ice will form on the idle areas and lead to blocked and eventually ruptured tubes. Therefore, the flow of air through the condenser sections is controllable by the use of three-piece covers for the air intakes to the condensers. Sections of the cover can be added or removed, depending on the outside ambient temperature.

Eight condensing sections are installed on each of two cars. Four blowers on each car draw the air from the outside through the condenser to a plenum chamber at the center and then discharge it upward. Each air discharge stack is provided with a hinged cover which is normally opened when its respective blower is in operation and can be closed when its blower is not in operation. This is to prevent recirculation when blowers are removed from service on account of low ambient temperature conditions. Each condenser car is equipped with a single-stage ejector and an air-cooled after-condenser. The chief function of the ejector is to keep air from collecting in the condenser sections, resulting in cold spots and possible ice formation.

In each individual condenser section there are ten rows of tubes divided into five groups of two rows each. This arrangement is an adaptation of principles developed in surface condenser practice to compensate for the varying condensing capacity as the air temperature rises during its progress through the condenser. If all the tubes were simply connected in parallel, the cold tubes would not be supplied with the amount of steam they are capable of condensing, while steam would be passing completely through the hot tubes and out through the vent. By dividing the tubes into groups and putting an orifice in series with each group, a small over-supply of steam to each group will put the controlling pressure drop at the orifice rather than across the tubes, and the tendency toward poor steam distribution is damped out. Excess steam passing through the orifices of the first four groups of tubes is condensed in the fifth group which serves as an "air cooler." The usual practice of putting the air cooler at the coldest part of the



Sketch of turbine car with main unit, switchboard and 75-kw diesel set



Plan and section of one of the boiler cars

condenser is reversed here to prevent freezing. Condensate dropping from the tubes is reheated and deaerated by the incoming steam before it is picked up by the condensate pumps and returned to the boiler.

TURBINE-GENERATOR CAR: The turbine-generator car contains the main turbine-generator unit, an auxiliary diesel-generator unit, a service transformer and switchgear equipment.

The main turbine is rated at 5000 kw and is designed for using steam at the throttle of 600 psi gage, 750 F total temperature and exhaust at 2 psi gage. The generator delivers power at 6300/10,900 volts, 50 cycles, 0.8 pf, 3000 rpm and 6250 kva. It is equipped with air filters to aid in maintaining cleanliness.

Power for the train auxiliaries is furnished by the 750-kva, air-cooled transformer at 380/220 volts, 3-phase, 50-cycle, 4-wire. The transformer is connected to the 5000-kw generator through fuses and is provided with a low-voltage breaker assembly for motor and lighting service.

For use in starting up a 75-kw, 380/220 volt, 4-wire, 50-cycle diesel-engine-driven generator set is provided.

The totally enclosed metal-clad switchgear contains oil circuit-breakers for control of the main generator, the four high-voltage feeder circuits, and high-voltage fuses for the train service transformer.

AUXILIARIES: Car No. 4 contains the following auxiliaries.

1. Two 3600-rpm boiler feed pumps driven by Westinghouse steam turbines. Each pump will be capable of supplying 208 gpm of 200 F water against a total head of 1770 ft.
2. One evaporator unit of sufficient capacity to provide the required makeup of 2400 lb per hr of 32 F. A deaerator to remove the air from the makeup, and a small motor-driven water pump for delivering treated water to the evaporator are included.
3. One set of water-treating equipment.
4. Three 400-cu ft per min air compressors—one driven by a direct-connected 100-hp induction motor and the other two by turbines through speed-reducing gears. The compressors will supply air to operate the boiler stokers, coal spreaders and soot blowers.
5. Air storage tank, water-cooling tower and pump.

BOILER FEEDWATER: The boiler feedwater car, which is thermally insulated and provided with heating coils, has a storage capacity of 10,000 gallons. There are two motor-driven booster pumps which deliver feedwater to the supply line of the boiler feed pumps.

BOILERS: The two boiler car units are essentially duplicates and are arranged so that the stoker ends are adjacent to each other. Each boiler car contains:

1. A 40,000-lb per hr, two-drum, bent-tube boiler with water walls, superheater and economizer, designed for 660 psi gage, 750 F steam and feedwater entering the economizer at 200 F. The boilers were designed and built by Combustion Engineering Company.
2. Soot blowers and a locomotive-type stoker. These devices are air operated in order to minimize the amount of makeup water.
3. Two 9900-cfm motor-driven forced-draft fans and one two-speed, 46,000-cfm motor-driven induced-draft fan.
4. Necessary measuring instruments and control equipment.

Service Car: The service car provides living quarters for the operating crew and space for light repair work

Boilers of the 5000-Kw Trains

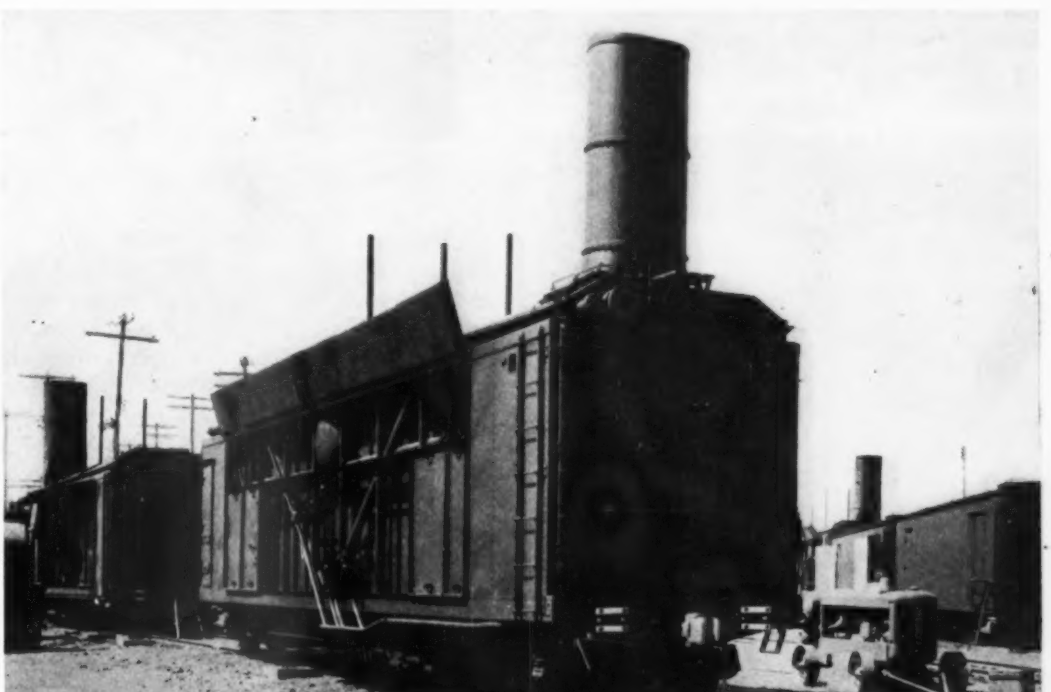
The talk by Mr. de Lorenzi was extemporaneous and included numerous slides showing details and construction views. In the absence of a prepared text by Mr. de Lorenzi we are privileged to quote from the following notes supplied by A. R. Smith, of Combustion Engineering Company, who has been intimately associated with this work and who deals particularly with the novel requirements and the steps taken to meet them.

In the basic design of these steam generators, experience in the field of locomotive practice has been drawn upon as concerns the fuel-burning equipment which comprises a Standard locomotive-type spreader stoker, a Hulson-type locomotive grate, a fully water-cooled furnace, and a locomotive-type combustion arch. The boiler is of the bent-tube type of novel design, having a four-steam pass drainable superheater, and a marine-type extended surface economizer. These components may be readily identified in the sectional view. Serving this combination are both forced- and induced-draft fans of conventional design, a water-level regulator, and the necessary instruments of the indicating type.

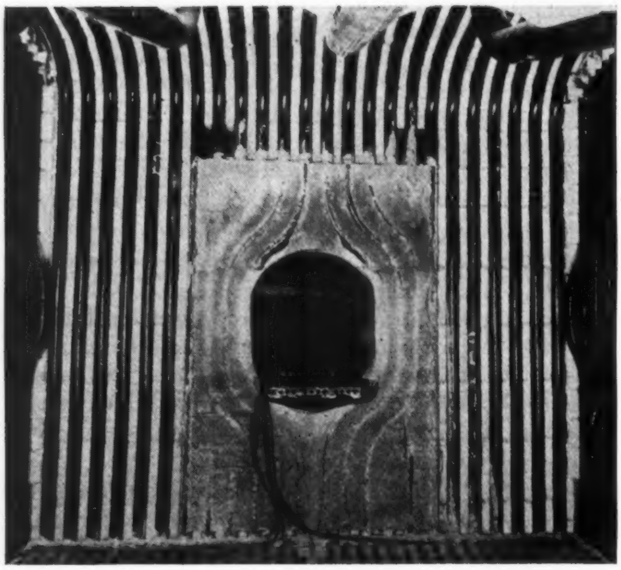
The boilers are small, from the standpoint of weight and physical dimensions, compared with conventional stationary practice for an equivalent steaming capacity; and are the largest so far constructed for burning solid fuels in mobile railway operation. The steam demand of each is roughly that of a Liberty ship at full speed.

The two principal limitations in order of importance are size and weight. Size is governed by domestic and foreign railway clearances and by allowable car length. Weight is governed by permissible axle loadings abroad. Broadly speaking, allowable cross-section is that of a domestic box car with a length allowance of 52 ft. Weight allowance in transit on the rails is 189,000 lb which must be equally distributed between the trucks. The position of the center of gravity of the car must be at the center of the car within close limits. Of the total weight, it has been necessary to allow 75,000 lb for the car structure, leaving only 114,000 lb for the equipment. The scale weight of the completed car ready to operate, but exclusive of coal and water, is 202,000 lb, or an apparent overweight of 13,000 lb. When operated over domestic trackage, this overweight is of no consequence as the rated capacity of the car is 140,000 lb. When operated abroad, however, the more stringent limitation of 114,000-lb load is met by unloading to other cars those items which are readily removed such as grates and arch tile and also those pieces of equipment which are normally removed in transit, such as ash pans, soot-blower heads and stacks.

Space limitations have imposed important restrictions on furnace and grate design. The size of the furnace has been governed by the maximum permissible width, height and length. Length and height are governed by railway clearances. Maximum furnace length is governed by the ability of the spreader stoker to throw the coal when operating on compressed air. In the present case, the furnace volume including that which is between the arch and first pass is 553 cu ft and the corresponding heat liberation at design load of 40,000 lb per hr is 133,000 Btu per cu ft per hr. With the furnace heat release rate imposed by the conditions, it becomes necessary to design the extent and disposition of black surface accordingly. A maximum amount of cooling is provided to keep the furnace temperature within limits that will prevent slag formation. The illustrations indicate the steps which have been taken along these lines. One shows the stoker end of the furnace with complete cooling, the tubes being spaced as close as will permit them to be drawn out around the stoker distributor plate. At all



Boiler cars in yard, completely assembled



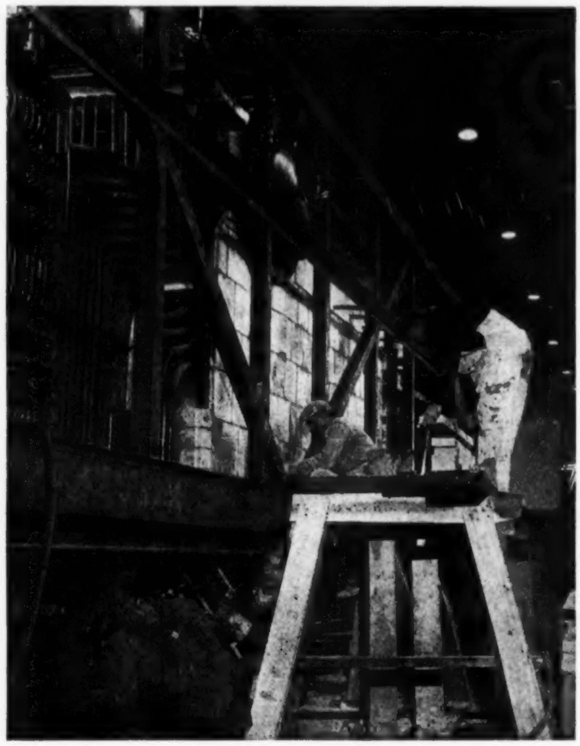
View in furnace looking toward stoker; refractory has since been removed

other points the tubes are even closer. The arch assures high turbulence and control over excess air. It prevents stratification and laning by creating a crossing of gas streams from the front and from the back of the furnace.

The maximum grate size possible is 107 sq ft which is within suitable limits in so far as the combustion rate at design capacity is concerned. This is 90 lb per sq ft per hr. This seems very high when compared with stationary practice but a study of locomotive practice reveals that still higher rates would have been permissible.

One of the requirements which was imposed on the design of the train, and as such on the design of the boiler cars as well, was that very little water might be available at the operating sites; hence makeup was limited to a few per cent. Ordinarily the stoker engine and stoker jets, as well as the soot-blowers would be steam operated. To avoid waste of water for such purposes air operation was adopted for all three. Air is made available by compressors located elsewhere on the train and piped to the boiler cars. It was found, however, that the total requirements exceeded the compressor capacity that could be installed without water cooling. But as the air requirement of the stoker engine diminishes with increasing temperature, the maximum compressor capacity was supplemented by an air preheater using waste heat. This preheater handles the compressed air to the stoker engine and jets and is located in the duct immediately below the economizer. A temperature of 450 F was judged adequate. Not only did the preheater save on equipment, but also weight and compressor power.

The use of preheated air in a reciprocating engine designed for steam posed a problem in lubrication. Since a prediction of results which might be expected was hazardous, it was deemed wise during design stages to make a full-scale set-up to test not only this point but also the effect of substituting air for steam at the distributor plate and to determine the quantity of air required to operate both engine and jets. As far as is known, stokers of this type had never before been operated on air. A suitable oil which would neither carbonize nor gum the valves was found. Calculated air requirements of the steam engine were confirmed, and the length of practical coal throw was established.



Applying insulation to side of boiler car

Furnace looking away from stoker, showing arch, grate and water walls

A final important limitation imposed on the entire structure is the high strength requirement in a horizontal plane in the front and back direction of the car to withstand railway shocks. A similar limitation has occurred in isolated cases where stationary boilers have been designed to withstand earthquake shocks.

All principal loads such as boilers, water walls, economizer and superheater are carried from above, the sides of the cars being framed as girders with suitable cross-bracing in the horizontal plane of the roof and in several

cross-sectional planes across the car where they would not interfere with operation of equipment or access.

Preliminary tests on these power trains indicate that expected performance will be met.

1000-Kw Power Train

The 1000-kw Westinghouse power train unit as described byMr. Laffoon and Mr. Ely, consists of one boiler car, one turbine-generator car, one cooling-tower car, and coal-handling equipment. The boiler is of the two-drum water-tube type, similar to that furnished for stationary practice by Babcock & Wilcox Company, and is designed for 420 psi, 730 F steam. This car also includes a locomotive type over-feed coal stoker, a steam-operated stoker feed engine, a motor-driven induced-draft fan, water-treating equipment, auxiliary steam-driven boiler feed pump, coal hopper and water storage tank.

The turbine-generator car contains a 1000-kw, 0.8-pf, 350-kva, 3-phase, 50-cycle, 1000-rpm, 6300-volt Westinghouse steam turbine designed to use steam at 400 psi, 725 F temperature and exhaust pressures of 2 to 5 in. mercury absolute pressure.

The following additional equipment is also located on this car.

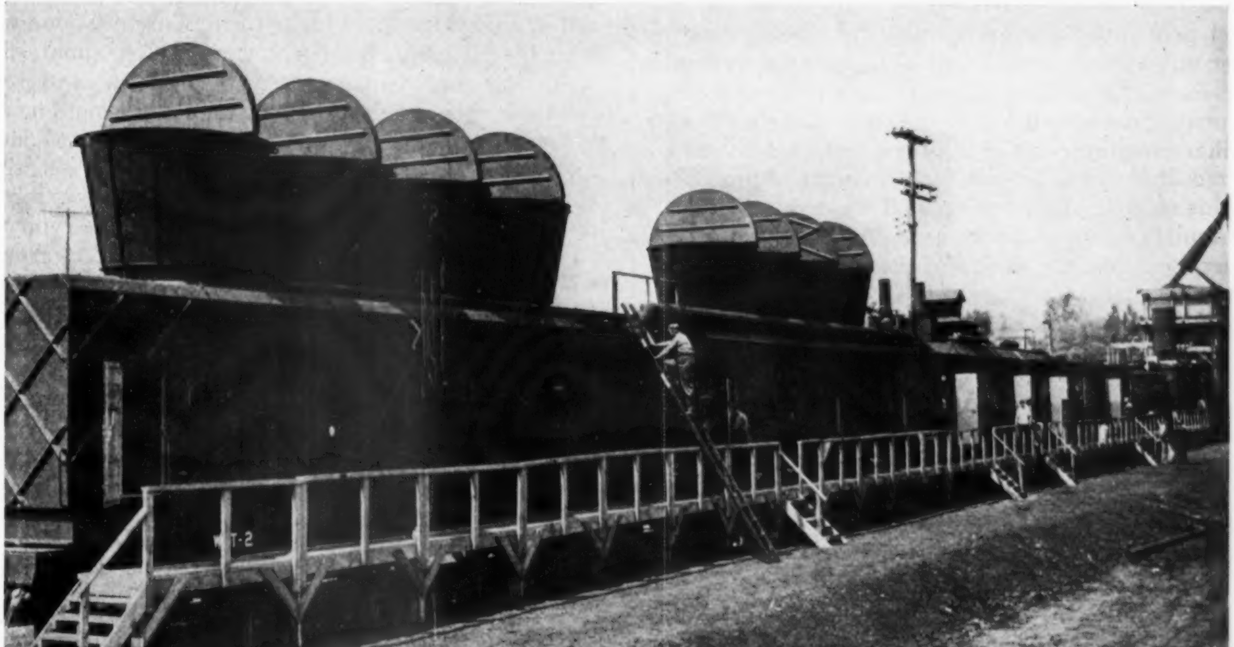
1. An 1100-sq ft, 3-pass semi-radial flow-type Westinghouse condenser with non-divided water boxes and a motor-driven condensate pump. The deaerating hot-well is mounted directly beneath and forms an integral part of the condenser.
2. A motor-driven boiler feed pump.
3. 6300-Volt metal-clad switchgear, including oil circuit-breakers for control of two feeder circuits and the main generator circuit.
4. A 125-kva, 380/220-volt, 3-phase air-cooled transformer connected through fuses to the main generator bus is provided as an auxiliary power supply.
5. A 5-kw, 3-phase, 380/220-volt gasoline engine-generator set is provided for use in starting up and for emergency auxiliary power service.

The cooling-tower car supports a two-cell induced-draft type cooling tower. Each cell contains two motor-driven vertical fans and between the cells is located a common vertical motor-driven condenser-circulating-water pump. The cells and super-structure of the car are of California redwood. The cooling towers are designed so that when reaching the point of ocean shipment, each section can be removed from the car as a unit and shipped on the lower decks of the ships.

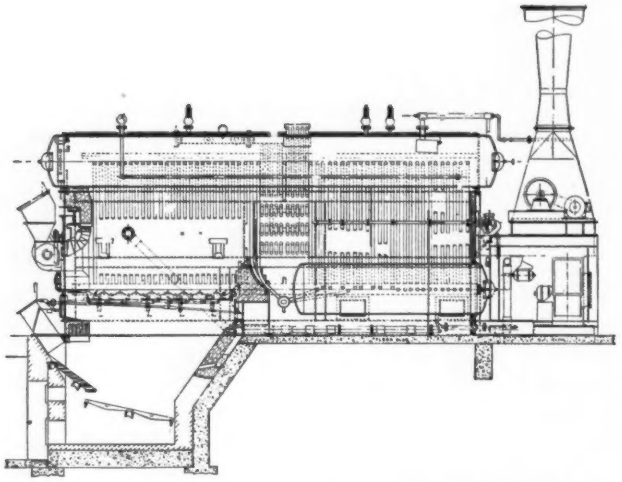
Package Type Power Plants

The "Package Type" power plant, as described by Mr. Wahrenburg, is made up of the necessary items of power-generation equipment, in relatively large pre-assembled units, each in itself mechanically and electrically interconnected, which can be conveniently transported to the required destination, and upon arrival can be aligned on a pre-installed foundation and rapidly made ready for power generation. The design requirements are: (1) that the packages have easy portability as to weight, size and shape; (2) that the equipment be grouped so as to facilitate rapid erection or dismantling; (3) that they be so arranged and grouped as to require a minimum amount of field work in making interconnections; and (4) that the design be as simple as possible and such that the foundations and enveloping structures can be of minimum extent. The sizes and weights of the packages are governed by transportation and handling facilities, railway clearances, etc.

The plant under discussion is of 500 kw capacity (476 kw net station output) and must be capable of utilizing the fuel most abundant in the designated locality. The



Train under test in yard with condenser cars in foreground



Section through boiler setting, showing Keeler boiler, C–E spreader stoker, and provision for burning wood

steam conditions are 300 psi, 700 F, condensing operation, and the designed plant heat rate was 31,000 Btu per kwhr; although on test a net heat rate of 27,500 Btu was attained. Electric energy is delivered at 400 volts, 3-phase, 50 cycles and 0.8 power factor.

The entire plant is divided into eight prefabricated functional units, each with its auxiliary equipment. These consist of a steam generator, turbine-generator, switchgear, condenser, spray tower, feedwater unit interconnecting piping and wiring, and fuel handling. The assembly occupies a floor area 34 by 55 ft. A total of twenty-four packages is required for the entire power plant—fifteen for the steam generator, three for the fuel-handling (including a crusher) and one each for the remaining functional units.

Steam-Generating Unit

The specification requirements for the steam-generating unit were particularly severe, inasmuch as it was necessary to make provisions for burning three fuels—wood, peat and coal of exceedingly low heating value and other adverse characteristics. The boiler was required to deliver 12,000 lb of steam per hour continuously, a quantity some 3500 lb per hr in excess of the turbine and auxiliary requirements, due to the fact that it was considered desirable to provide for a quantity of process and heating steam. And, finally, as it was assumed that the plant might be located in an isolated area with no outside power available, the design of the complete station had to be such that it would contain all of the elements necessary to bring it onto the line without benefit of outside power.

The unit selected consists of a boiler of the longitudinal drum type, with superheater in the first pass, no air preheater or economizer, a water-cooled furnace equipped with a spreader-type stoker for burning coal and peat, and a refractory furnace built under the water-cooled furnace, equipped with sloping stationary bar grates for firing wood.

The appurtenances consist of a forced-draft fan to supply air under the grate for peat and coal combustion, and over-fire air for wood burning; an induced-draft fan with venturi-type stack; cinder recovery equipment; and the usual complement of boiler accessories, including furnace draft regulator, feedwater-level control assembly, all piping up to and including the last blowoff valve, and the superheater outlet header. Both the induced- and the forced-draft fans are motor driven. However, in order to provide for bringing the unit onto the line and furnishing enough steam to start the turbine-generator and other plant auxiliaries, a steam aspirating jet-ring is provided in the throat of the stack.

The two major packages of this assembly consist of: first, the boiler, superheater and furnace proper; and, second, a rear assembly upon which are mounted the fans, a section of ductwork with dampers, and the lower portion of the stack. This latter package is arranged for easy positioning and attaching directly behind the boiler. In order to meet weight limitations, it was necessary to package the stoker fronts with the operating mechanism, and to package the grates separately. To meet physical clearance restrictions, the upper portion of the venturi stack and the section of forced-draft air duct along the side of the boiler had to be packaged separately.

Condensing Unit

The condenser assembly, which consists of one package, was designed for mounting on a flat slab located at the same elevation as the turbine-generator. A substantial, structural steel base is provided, and the condenser (of the two-pass surface type) is elevated above this base. Mounted on the base are motor-driven condensate and circulating water pumps. The after-condenser and two single-stage air ejectors are compactly arranged at the side of the assembly. All of the interconnecting piping between the elements of the unit is installed in operating position.

Spray Tower

Because of the varied and uncertain nature of the quantities, qualities and temperatures of available condenser circulating water, it was determined that provision should be made for cooling the circulating water. The availability of a river or similar source of supply was not depended upon. Employment of a spray pond would have placed a large burden of work at the ultimate site in preparing an adequate and satisfactorily water-tight reservoir, while the use of a cooling tower would have involved a considerable quantity of intricate woodwork assembly. A compromise was reached by selecting a spray tower which simplified the woodwork assembly and also reduced the foundation and concrete reservoir work to a minimum. As any and all woodwork was to be supplied in the field, the spray-tower equipment consists of the piping, spray nozzles and the hardware necessary to assemble the woodwork. All of this material was conveniently combined in one case.

In order to meet a wide range of climatic conditions, with temperatures as low as −50 F, provisions were incorporated in the design of the spray tower for segregating, recirculating, and the like, of various portions of the water.

Feedwater Assembly

The essential elements of this assembly are: (1) a pressure filter of 14 gpm capacity; (2) two zeolite softeners; (3) two duplicate back-wash pumps; (4) a spray-type deaerating feedwater heater; and (5) two 40-gpm, steam-driven boiler feed pumps.

Fuel Handling

Given a good quality of coal, it would not have been necessary to furnish any facilities for fuel- and ash-handling beyond wheelbarrows and shovels. The fact, however, that exceptionally low-grade coal (5900 Btu per lb) and peat (5000 Btu per lb) as well as wood (5000 Btu per lb) may be involved, indicated that large volumes of fuel will have to be moved. Consequently, conveying equipment of the tramway-bucket type was furnished, together with a portable conveyor for unloading coal to a raw coal bin. With each of these plants a coal and peat crusher was provided, as it is not always possible to obtain prepared sizes of coal and peat at the various plant sites. The portable conveyor also will be used to deliver coal from the crusher discharge to the prepared peat and prepared coal bin. Cord wood can be moved into position for hand firing by substituting slings for the bucket of the tramway system. All coal bins are temporary wooden structures.

The necessity of providing for wood burning complicated the general arrangement to a material degree, and accounts for several of the fifteen packages required.

The wood-burning provisions are rather unique. It was contemplated that in some cases green logs will be burned, cut from adjoining forests, if necessary, and having a length of 30 in. and a diameter not exceeding 8 in. These logs will be manually introduced into the furnace through an air-locked magazine. Natural draft will furnish the primary air, and the forced-draft fan will furnish the over-fire air.

Turbine-Generator and Switchgear

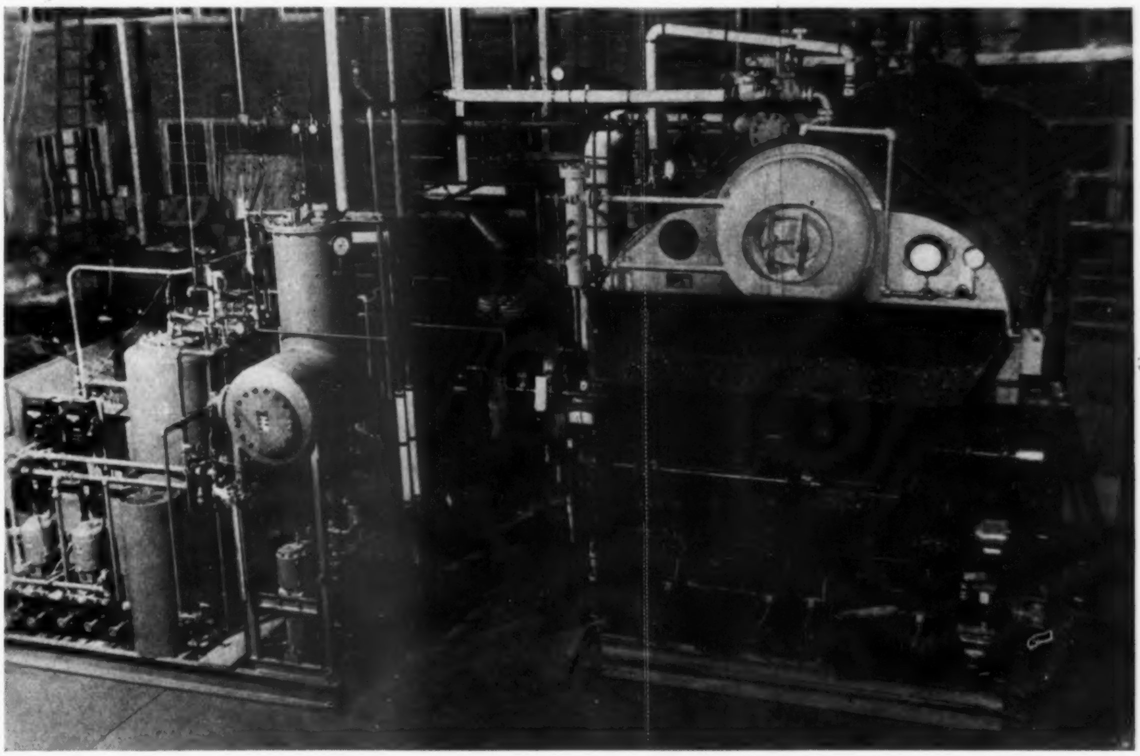
There were no particular difficulties encountered with respect to packaging the 500-kw turbine-generator. A top exhausting arrangement is used, in keeping with the desire to simplify foundation structures, and for the same reason the turbine-oil reservoir and piping are held above the floor line. A continuous structural-steel bedplate is provided and can serve as a skid for moving the unit.

The control panel is arranged in one unit, and is of the dead-front, totally enclosed, steel type. A substantial steel base is provided to facilitate moving it without distortion of the panel and enclosure. More than the usual number of outgoing feeder circuits are provided, as the distribution from this board is naturally indeterminate. The usual protective devices are provided, together with the necessary indicating voltmeters, ammeters and the like, and a watthour demand meter is provided to measure the generator output. Each outgoing feeder has a current transformer in one leg of the circuit.

A basic premise was that the load center would be close to the plant, and distribution is therefore at 400 volts; however, in order to provide for some cases where this might not be entirely true, some of the plants are provided with a 300-kva, 3-phase, step-up transformer to 6600 volts.

This package-type power plant was so designed as to permit its complete assembly within a period of 36 hr.

The basic procedure for starting-up consists of firing the boiler by hand, starting with natural draft, then supplying additional draft when sufficient steam pressure is available to furnish steam for the steam ring in the stack. When 50 lb pressure is available, the boiler feed pump will operate. At a higher pressure the turbine-generator is started exhausting to atmosphere, and generates sufficient electrical energy to operate the fans and stoker electric drives. The steam-generating unit will generate approximately 4700 lb of steam per hour at 300 psi without fans. This quantity of steam will permit about 100 kw generation, operating with atmospheric exhaust.



Package-Type plant completely assembled for test

Fuel Problems Discussed by A.S.M.E.

The extensive and varied program of the A.S.M.E. Semi-Annual Meeting at Pittsburgh, June 19–22 included two well-attended sessions on fuel at which timely papers were presented. These dealt with the selection of coal, the wider use of small anthracite, coal segregation, and factors affecting the thickness of slag on furnace walls. Abstracts of these papers follow.

Coal Selection

THE coal suppliers' viewpoint was expressed in a paper entitled "Fuel Investigation Precedes Power Plant Design" by **E. C. Payne,** consulting engineer of Consolidation Coal Company. This dealt with fuel facts which should be developed prior to the planning of new power plants or the modernization of old plants—a program which can begin as soon as critical materials are released for civilian needs. Prices obtained today, under wartime demand and controlled OPA regulations, the author cautioned, cannot be indicative of the relative utilization values. However, a fuel investigation should go much deeper than price and quantity required. The first step is to obtain complete information on all the grades of coal that are competitively available and, in laying out a power plant, the equipment should be selected to use a range of quality rather than be restricted to the use of a particular coal with limited reserves.

Well-designed steam-generating equipment can be expected to utilize average coal efficiently, regardless of special characteristics, so there seems to be no point in planning to use a premium coal. Users of fuel oil and specialty coals have discovered during this war that such fuels were conscripted first for essential services. Such experience should cause one to be cautious in future designs, so that the plant may have sufficient flexibility and capacity to carry the necessary load with normal quantity steam coals.

Furthermore, long-range purchasing must be considered. When coal is selected for a new power plant, one must be assured that it will be readily available for a long time, as some of the mines, particularly those producing high-fusion, low-volatile coals will be exhausted within the next few years. On the other hand, tremendous reserves are available in the low-fusion, high-volatile coals.

Usually the primary selection will include a number of mines from the same seam, producing coals of substantially the same quality, but one or more alternative sources of supply, as a secondary selection, permit competitive purchasing.

The fuel study will reveal that the majority of coals from a certain seam in a particular region will be produced in various sizes, and that one or more sizes will provide the lowest cost per million Btu for pulverized fuel use—$^1/_4$ in. × 0, $^3/_8$ in. × 0, $^3/_4$ in. × 0. Slack sizes will probably be better values than the $1^1/_4$ in. × 0 or 2 in. × 0. Because of seasonal demands, it may be important to design for the utilization of a maximum size of 2 in. × 0. The margin between the price of slack and run-of-mine is diminishing every year and it would be well for the large steam plant of the future to install crushing equipment for final sizing.

The proximate analysis should represent the average quality of the coal to be supplied. All coal seams vary in chemical quality and even in the same location there may be wide variation; but the producer can compensate for this by blending and thus ship quite a uniform product whose quality will vary within narrow limits. The Btu value and ash-softening temperature should be included with the proximate analysis.

It is also desirable that the designer know the friability of the coal, or its resistance to degradation in handling, so that the conveying equipment may be properly designed. Grindability is also a determining factor in establishing pulverizer capacity. Other factors that should be known in advance of plant design are the caking characteristics of the coal, its clinkering and slagging tendencies and the probable corrosive characteristics of the gases of combustion.

Mr. Payne cautioned that purchase of power plant and combustion equipment on the basis of low first cost is a short-sighted policy. Equipment that will permit reasonably wide latitude in fuel purchasing must be liberally designed, and if the range of coals selected as a result of the fuel investigation are to give operating satisfaction, the manufacturer must not be required to cheapen the installation in order to meet price competition. Moreover, liberal capacity should be provided to carry the anticipated steam demands with the primary or secondary fuels, so that there will be no necessity for purchasing premium coals.

The fundamental consideration must be "dollar efficiency" which is the total overall cost per thousand pounds of steam generated; and in this connection it is sometimes desirable to sacrifice thermal efficiency for economy.

Increasing Use of Small Anthracite Sizes

Under present conditions of accelerated production among the anthracite mines there is being built up a large surplus of small industrial sizes over the normal demand as dictated by installed equipment suitable for burning such fuel. This ranges from No. 3 buckwheat (barley) down through the smaller sizes. It is of deep concern to the Solid Fuels Administration to move this growing accumulation by finding new markets in order that the needed production of domestic sizes shall not be cut and that available supply of bituminous coal may be supplemented to meet the demands of war industries. Accordingly, the surplus tonnage is being purchased by the Defense Supplies Corporation of the Government and is being marketed by the Solid Fuels Administration at prices equal to those of bituminous coal on a Btu basis.

The following tabulation, presented in a paper by **J. F. Barkley,** and **William Seymour,** of the U. S. Bureau of Mines, gives approximate tonnages for the different sizes of small anthracite sold for various uses in 1943. Attempts are being made to increase the use in these several categories and, if possible, to develop other uses. Four projects upon which the Bureau of Mines is now actively engaged are (1) the burning of mixtures of small anthracite and bituminous slack on stokers; (2) methods for the production and burning of "packaged fuel" from anthracite fines; (3) use of anthracite fines in the production of coke; and (4) use of barley anthracite in gas producers.

	Size		
Use	$^3/_{16} \times {}^3/_{32}$ Barley	$^3/_{32} \times {}^3/_{64}$ No. 4 Buckwheat	$^3/_{64} \times X$ No. 5 Buckwheat
Overfeed stokers	4,560,000	1,447,700	0
Underfeed stokers	504,900	458,000	0
Pulverized coal	0	654,600	481,500
Hand fired	424,900	5,400	0
Mixed with bituminous coal	1,900	16,900	0
Briquetting	4,400	263,800	11,400
Ore sintering	98,300	84,000	74,700
Mfg. carbon electrodes	15,200	800	800
Mfg. chemicals	1,100	0	0
Mfg. foundry facings	0	0	2,700
Coke blending	0	0	16,300
Special uses (not specified)	113,300	5,700	2,700
Total	5,724,000	2,936,900	590,100

With reference to the burning of mixtures on stokers of the underfeed type, it was pointed out that bituminous coal in the eastern region of anthracite availability is generally of the caking variety with considerable range in volatile, ash, ash-fusion temperature and Btu content. Therefore, the addition of barley would be expected to decrease caking, decrease pressure drop through the fuel bed, decrease manual attention to the fuel bed in the case of single-retort stokers, decrease smoke, increase fly ash and combustible in both the fly ash and refuse, affect clinkering favorably and have some influence on both load-carrying capacity and overall efficiency. The extent would, of course, depend upon the percentage of anthracite used.

The effect on caking by adding a small percentage of anthracite is of more consequence with single-retort stokers, with or without side dumps, than with multiple-retort stokers having the end dump and greater adjustment possibilities. The addition of about 15 per cent anthracite barley in the case of single-retort stokers has been found to open up the fuel bed and give little trouble from caking.

As to load-carrying capacity, if the bituminous coal has a higher Btu content and lower ash than the barley, the heat value of the mixture is decreased somewhat and the quantity of ash to be handled is increased. Also, the anthracite is slower burning. These factors may mean less load-carrying capacity; but, on the other hand, improvement in caking qualities will tend to offset this handicap when relatively small percentages of anthracite are employed. However, if the bituminous coal is as high or higher in ash content than the barley, larger percentages of the latter may be employed effectively.

Gains in fuel-bed conditions through the addition of anthracite will tend to offset an increase in unburned combustible and in some cases the proper mixture may result in a somewhat higher efficiency than when burning straight bituminous coal of the caking type. The optimum mixture can be determined only by actual trial for each installation and attention must be given to the proper stoker and damper adjustments.

The problem of mixing is important and must be done at the plant. Although a completely uniform mixture is seldom attainable, care should be taken to avoid segregated patches of anthracite and the higher the percentage of anthracite the more careful must be the external mixing. Dumping in layers is desirable, and a series of conveyors assists in the mixing which is further aided within the stoker itself.

Packaged fuel (briquets) chiefly for domestic use, has been manufactured largely from Pocahontas screenings. Recently, the Bureau of Mines, in cooperation with a large industrial company, has been experimenting with the production and testing of packaged fuel containing various percentages of anthracite fines. No major difficulties have been encountered. Tests have shown that when the percentage of anthracite reached 70 to 80 per cent the blocks did not fuse and were entirely free burning.

The annual capacity of gas-producer installations employing anthracite is about 45,000 net tons of buckwheat and 600,000 net tons of rice. It has been estimated that a market for not less than 300,000 tons of barley might be developed as a result of experiments now in progress for the substitution of barley in place of the larger sizes now used.

Coal Segregation

Coal segregation in boiler plants leads to fuel waste, increased maintenance and limits maximum steam output. These points were discussed in a paper by **Arthur J. Stock,** President of Stock Engineering Company, who showed by slides how segregation takes place, how it affects the process of fuel burning, and how it may be overcome.

Segregation means the separation of the larger particles of coal from the finer particles and, if this continues into the furnace, combustion will become irregular because of the different burning characteristics of the different sizes of coal. It adversely affects underfeed and traveling-grate stoker operation, not only because ignition of coarse coal proceeds at a different rate from the fine coal, but the resistance of the fuel bed to the flow of air varies according to the fuel size. Those portions of the fuel bed containing coarse coal burn faster and provide burned-out spots through which air can pass without having opportunity to combine with the fuel. Also, this exposed section of the stoker may become overheated and result in burned iron. On the other hand, where accumulations of fine coal exist, combustion proceeds at a slower rate and combustion may be incomplete when the ash is dumped. This results in a high combustible content in the ash. In some cases segregation may also cause clinker formation because portions of the fuel bed burn at higher temperatures than others. This is particularly true where low-fusion-ash coal is burned.

On a spreader stoker uniform size distribution is important, for if distribution is not uniform, a clinkering tendency will be noted wherever there is piling. Adjustment in the speed of the flipper is provided for changes in size of fuel; that is, when the fuel runs large, the speed must be slowed down and when it runs fine the speed must be increased. Where more than one feeder serves a furnace, it is customary to run all feeders from a single lineshaft, which means that no individual unit can be varied in speed. Hence, uniformity of feed to the

several hoppers is important to avoid one feeder throwing too far and another not far enough.

Coal segregation will result in variation in gas velocities and temperatures across the furnace and, in the case of chain grates it is likely to cause severe damage to refractory arches.

While chute segregation is not important in the case of pulverized coal, segregation in the bunker tends to affect the grinding capacity of the mill, particularly where considerable surface moisture is present.

The amount of segregation in any installation depends upon the kind of coal, the size distribution, moisture, velocity, and both size and shape of the passageways through which the coal flows. The following illustrations represent how segregation occurs with different types of equipment.

Fig. 1 shows segregation in a typical flat chute which results in a coarse coal streak down the center of a chain grate as in Fig. 2, caused by the meeting of two flat chutes.

Fig. 3 represents segregation in a coal bunker fed by a flight conveyor without a trough. The conveyor fills the left end first, a pile is formed, and the top moves toward the unfilled end; this puts the coarse coal on the right-hand side.

In the case of a steel cylindrical silo, with a vertical center feed, the fine coal collects in the center, as shown in Fig. 4, and when coal is withdrawn, this comes out first followed by a mixture which progressively becomes coarser. With a concrete silo such as represented by Fig. 5, which is fed from the side, the coarse coal gradually rises to the top of the down-spout and is projected to the far side of the silo. For a similar reason, the condition of Fig. 6 often occurs where two single-retort stokers are fed from a single down-spout.

Segregation may occur within an apron-feed hopper coal scale. That occurring in a flat chute fed from an inlet flange at one side is shown in Fig. 7, and Fig. 8 represents the form of segregation that may result from an infrequently operated weigh larry. This produces a coarse coal seam that runs across the flow of coal. A similar pattern may be caused by a screw conveyor that is installed across the top of the stoker hopper and operated only periodically.

Fig. 9 represents the character of fuel bed resulting from use of a typical flat chute, with coarse coal at the sides and fine coal in the center; and Fig. 10 shows the type of fire that results when the coarse coal is all on one side.

Eliminating Coal Segregation

Bunker segregation, in general, can be eliminated to a degree by multiple points of loading. In the case of a flight conveyor (Fig. 3) a trough should be provided with outlet gates which can be opened and closed in such a manner that the bunker will be loaded in horizontal layers instead of from one end.

In the case of a silo with center feed (Fig. 4) or a concrete silo as shown in Fig. 5, it is often possible to reduce segregation by the employment of chutes within the silo or bunker which carry the coal to several points. These chutes are built with open tops so that when the bunker or silo is nearly full the chutes are flooded.[1]

[1] This method was employed at the University of Illinois and described in a paper on "Segregation in the Handling of Coal," by David R. Mitchell, A.I.M.E. Technical Publication No. 846.

In order to eliminate segregation in down-spouts feeding two or more stokers, a vertical division of the coal flow should be made as shown in Fig. 11. Segregation caused by coal scales can be avoided by so arranging the scales that the feed belt runs toward or away from the boiler front.

Some plants employ hand-swing spouts, but these are usually limited to small installations. When used, best results are had when the spout is swung frequently and the coal valve at the outlet should be closed after the spout is swung. It is possible to install a plate across the center of the stoker hopper to stop the flow of coal when the spout is in the vertical position, such a plate being equivalent to an automatic coal valve. Mechanically operated swinging spouts are also available and give satisfactory results if the spouts are swung the full width of the stoker hopper and if the speed of the spout is reasonably rapid.

Baffles of various forms have been installed within the flat fan-shaped chutes. In some cases they help a little whereas in others they impede the coal flow to such an extent as to be unsatisfactory.

Some plants have employed a chute the full width of the stoker hopper and extending up to the bunker. Inasmuch as there is no change in cross-sectional area such a chute will not cause segregation within itself, but with such a design it is imperative that there be no bunker segregation. Likewise, the length of the bunker should be substantially the width of the stoker hopper.

Weigh larries can be employed to avoid segregation in stoker hoppers, but to do so they must be moved frequently from one side of the hopper to the other. It is also necessary to close the coal valve at the weigh larry hopper outlet so that the larry does not discharge freely into the stoker hopper when standing still.

A conical design of distributor has proved satisfactory in eliminating chute segregation. Its operation may be explained as follows: If the lump of coal were placed at the apex of a cone, the axis of which is vertical, and then released, it would slide down any element of the cone. Now if a number of pieces of coal were placed at the apex of the same cone and released, the condition shown in Fig. 12 would result, wherein all the coal regardless of its size or shape, would be equally distributed around the cone. A segment of the cone would produce the same result. But in order to deposit the coal along a straight line, the conical segment is cut by a vertical plate, as in Fig. 13. The coarse and fine coal remain uniformly mixed in this vertical drop, since the flow of the coal particles is parallel. The conical non-segregating coal distributor is formed by adding to such a conical segment two side plates, an entrance flange and another similar conical segment to act as a cover plate. Fig. 14 shows an installation of such a distributor.

Factors Affecting Thickness of Slag on Furnace Wall Tubes

Results of further studies of this problem as conducted at the Pittsburgh laboratory of the U. S. Bureau of Mines were reviewed in a paper by **W. T. Reid** and **P. Cohen** of that Bureau.[2]

The factors involved can be divided into two classes,

[2] A detailed report will be contained in a forthcoming Technical Paper of the Bureau of Mines.

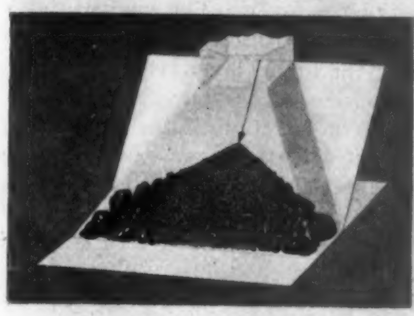


FIG. 1

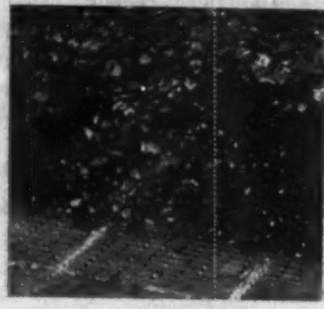


FIG. 2

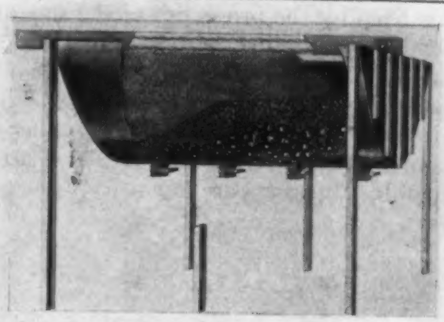


FIG. 3

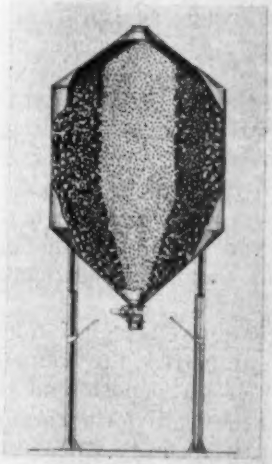


FIG. 4

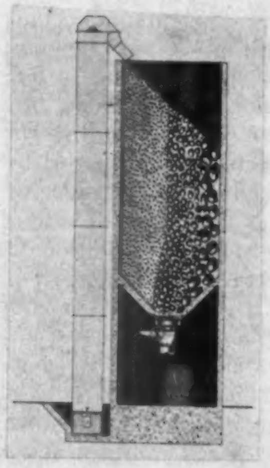


FIG. 5

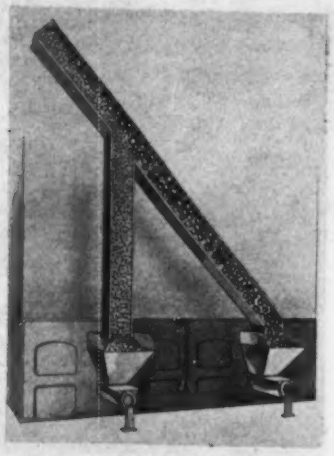


FIG. 6

FIG. 7

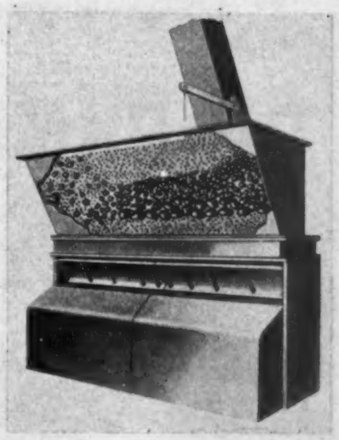


FIG. 8

FIG. 9

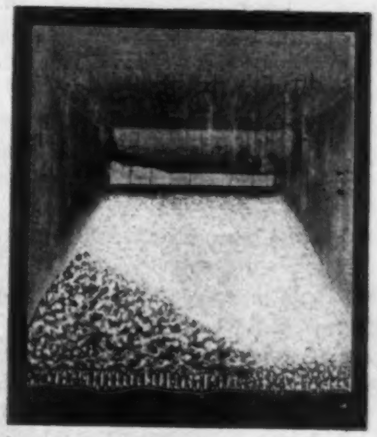


FIG. 10

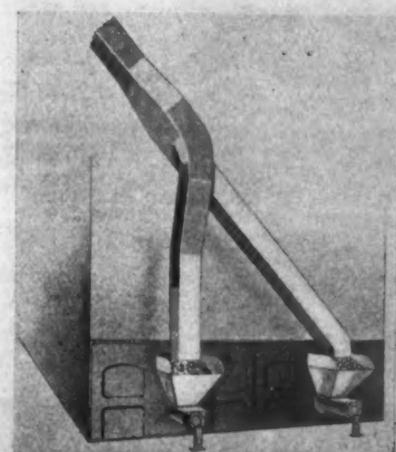


FIG. 11

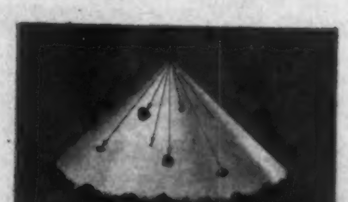


FIG. 12

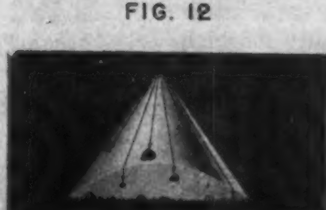


FIG. 13

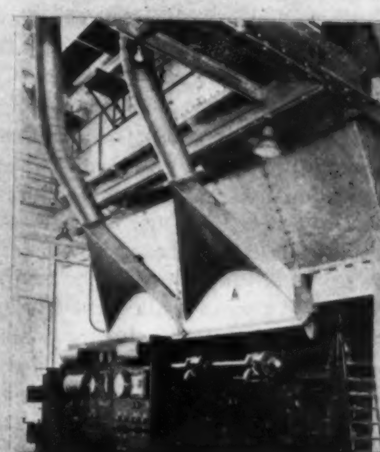
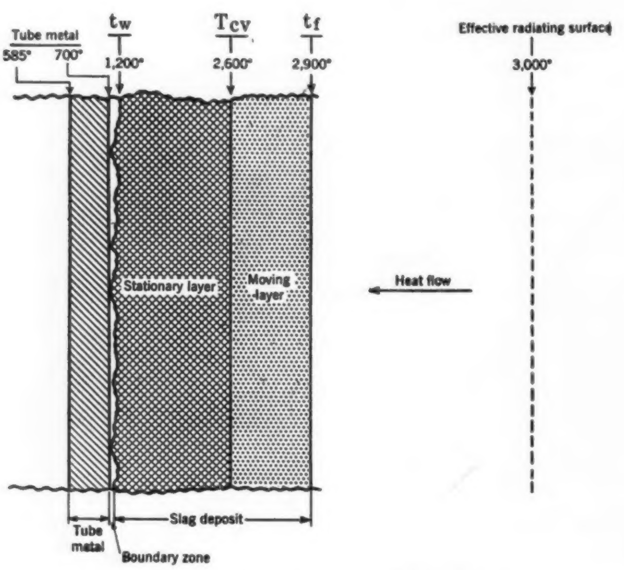


FIG. 14

one fixed by the properties of the slag and the other dependent upon furnace conditions such as the rate of supply of slag to the walls. Only that part of the furnace where the slag surface is molten and a continuous surface of slag occurs is considered, as other sections of the furnace where deposits break off after reaching considerable thickness are less susceptible to definite analysis.



Temperature distribution in slag deposit

Referring to the illustration which represents a typical deposit immediately adjacent to the surface of the tube, there is a thin, semi-porous, irregular layer of partially melted ash through which the slag adheres to the tube. Next, there occurs a dense, crystalline layer of slag which usually makes up the largest part of the deposit. Finally, there is a layer of glassy slag which extends to the surface, the boundary between it and the crystalline layer usually being sharply defined. The arrangement of these layers is the result of the temperature gradient through the slag which existed during operation of the furnace and does not result from events subsequent to taking the unit off the line, in which case the glossy layer would be next to the tube surface, having there been cooled most rapidly. That is, when a furnace is operating, the slag deposit nearest the tube is maintained at a sufficiently low temperature for the slag to crystallize, whereas on the furnace side the slag is molten.

Laboratory studies have shown that coal-ash slags are not true liquids over a wide range of temperature. Most slags on being cooled slowly, begin to separate solid material from the liquid condition. This solid matter, usually present as small crystals, causes the slag to become plastic rather than viscous, the essential characteristic of this plastic state being that a definite shear stress is necessary to produce flow. The temperature at which this transition occurs is called the "temperature of critical viscosity," Tcv, the value of which is determined for a wide range of composition of coal-ash slags.

In the flowing, liquid layer of slag, the low-temperature boundary will be at the temperature of critical viscosity, while the high-temperature boundary will be at the furnace temperature; thus there will usually be a temperature difference of several hundred degrees between the two sides of the layer. The viscosity of the liquid slag and its variation with temperature will determine the thickness of the liquid layer required to carry off the slag being supplied. As the temperature of critical viscosity increases, the fraction of the total deposit of slag which is stagnant will also increase and the thickness of the layer will be greater. Likewise, as the viscosity of the liquid layer increases at any fixed temperature, the rate of flow of the slag will decrease and the slag thickness will be greater.

Effect of Furnace Conditions

Factors other than the fundamental flow properties of coal-ash slag are important in fixing the thickness of slag on heat-absorbing surfaces. These include: (1) temperatures in the furnace and of the slag deposit, (2) amount of slag being supplied to the surface from the furnace gases per unit of time, (3) height in the furnace at which flow begins, (4) height at which the thickness of slag is to be considered, (5) angle of inclination of flowing slag, and (6) rate of heat transfer through the layer of slag. Additional factors dependent on slag properties rather than flow include the thermal conductivity of the slag and its density.

The authors presented an equation relating the thickness of slag deposit to the flow properties, the temperature of the hot and cold sides of the deposit and the volume of slag flow, from which the relative thickness of slag deposits for typical conditions can be calculated. This provides a means of comparing the behavior of different coal ashes on furnace walls.

Determining Amounts of Contaminated Material Entering Boilers

A measure of the contaminating impurities entering the boiler may be had from the relation of the concentrations of components of the treating chemicals and of the impurities remaining in solution in the boiler water. A simple expression is offered to illustrate this method.

By B. C. SPRAGUE

West Penn Power Co.

DISSOLVED solids and suspended matter in the station cooling water, which gets into the boilers as the result of condenser leakage and evaporator carryover, is likely to give rise to troublesome scale and sludge deposits. Hence, it is very important that such contamination be kept at a minimum. In guarding against preventable contamination of the boiler feedwater, it is very helpful to have a measure of the amount of contaminating material entering the boilers. Such a measure makes it possible to determine whether the contamination is greater than it should be from the known amount of condenser leakage and the expected average evaporator carryover. By maintaining a continuous record of such determinations, it is possible, by investigating any abnormal increases in the contamination not accounted for by condenser leakage, to locate and correct any of the various conditions which may from time to time result in impurities getting into the boilers.

It is theoretically possible to determine how much contaminating material gets into the boilers from the amounts and concentrations of the water removed from the boilers. However, this is usually very difficult in practice because the quanties of water in the blowdown and drained from boilers are not accurately measured and the taking account of the different concentrations of the various quantities of water removed involves a great many calculations. The quantity of chemicals added as feedwater treatment is sometimes taken as a measure of the amount of impurities. However, in modern high-pressure plants using evaporated makeup, the amount of chemical added to enter into combination with the calcium and magnesium salts may be several times that theoretically required because of the need to maintain minimum concentrations of the treating chemicals in the boiler water and the resulting elimination of uncombined chemicals in the blowdown. Hence, the quantity of treating chemicals added does not provide a satisfactory measure of the amount of impurities to be treated.

Where known amounts of treating chemicals are added to the feedwater, it is possible to obtain a satisfactory measure of the contaminating impurities entering the boilers from the relation of the concentrations of components of the treating chemicals and of the impurities remaining in solution in the boiler water. This measure is based upon the principle that, to the extent that various chemical components added to the boiler water remain in solution, their concentrations in the feedwater will have the same relation to each other as the amounts added. Where phosphate treatment is employed, the measure of contamination can probably most conveniently be based upon the concentrations of phosphate (PO_4) and sulphate (SO_4) in the boiler water. Since the phosphate treatment prevents the precipitation of sulphate salts, all of the sulphate in the impurities remains in solution in the boiler water. Some of the phosphate added enters into combination with the calcium and magnesium salts getting into the feedwater with the impurities and is precipitated from solution, leaving in solution the uncombined phosphate. Knowing the hardness and the sulphate concentration of the raw water, it is possible to adjust for the quantity of phosphate which will be eliminated in precipitating calcium and magnesium salts.

If we let k represent the ratio of the hardness (reported in terms of ppm of $CaCO_3$) to the sulphate (SO_4) concentration of the raw water, and P the total pounds of phosphate (PO_4) added to the feedwater as treatment over a period of time, then the total pounds of sulphate added to the water with the contamination is given by the equation:

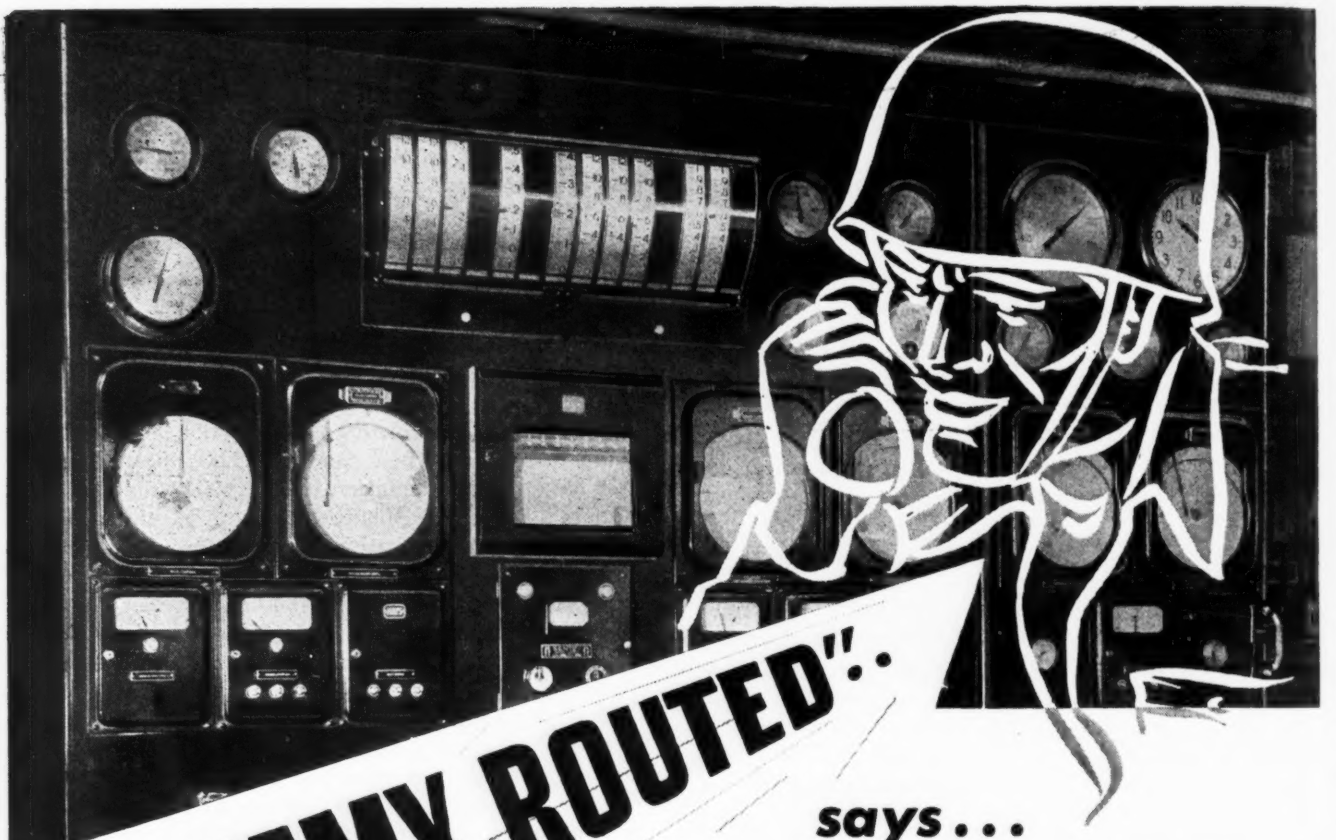
$$\text{Sulphate (pounds)} = \frac{P}{\dfrac{(PO_4)}{(SO_4)} + \dfrac{190}{300k}}$$

where (PO_4) and (SO_4) represent, respectively, the phosphate and sulphate concentration in the boiler water, reported in parts per million.

Knowing the ratio of sulphate in the raw water to the dissolved solids, the total solids, the hardness, or any other component of the contamination it is desired to measure, and the ratio of phosphate to total weight of the treating chemical, a simple equation can be set up which will give the weight of any component of the contamination directly from the weight of treatment chemical added. For example, if monohydrate trisodium phosphate ($Na_3\,PO_4\text{-}H_2O$) is the treating chemical the ratio of phosphate weight to the total chemical weight is as 95 is to 182 or 0.52. If the total concentration of dissolved solids in the raw water is equal to 2.5 times the sulphate concentration, then the pounds per week of dissolved solids entering the boilers is equal to

$$\text{Dissolved solids per week (pounds)} = \frac{2.5 \times 0.52 \times (Na_3\,PO_4\text{-}H_2O) \text{ in lb per week}}{\dfrac{(PO_4)}{(SO_4)} + 0.63k}$$

(Continued on page 47)



Since the above measure of contamination is dependent upon change in ratio of various components in the boiler water concentration, it will be apparent that it will not immediately reflect the entrance of contamination. However, the few days' lag in reflecting contamination does not destroy the usefulness, especially since some indication of a change is given as soon as it has had any material effect upon the boiler water. The measure becomes more accurate the greater the length of period for which it is applied. Reasonably satisfactory results may be obtained for weekly periods based upon a single determination of the sulphate and phosphate concentrations in the boiler water, or using the average of several determinations in the week if available.

To minimize the effect of treatment added to boilers upon filling, the sulphate and phosphate concentrations in the boiler water should be based upon the averages from boilers that have been in service some time since refilling. When the phenomenon sometimes referred to as "hide-out" is experienced, resulting from some normally soluble salts temporarily remaining precipitated on the boiler surfaces during operation at high ratings, the boiler water concentration data should be based upon samples taken during periods of reduced boiler rating. In cases where some or all the magnesium entering the boilers with the contaminating solids is precipitated as magnesium-silicate rather than as magnesium-phosphate, as assumed in developing the above equation, the equation can be adjusted to take account of this if the magnesium is large enough in relation to the calcium to make this advisable.

X-RAY DIFFRACTION—
A New Industrial Research and Control Technique

The importance of identifying the chemical compounds comprising solids deposited on steam-generating surfaces and turbine blades cannot be overstressed, and the X-ray diffraction technique is unique for this purpose. To supplement recent articles in industrial publications which describe the uses of this relatively new analytical tool, the present article will describe in simple terms the theory and the application of X-ray diffraction. It will be directed primarily to technical personnel whose work is related to the production and the utilization of steam.

By R. C. COREY

Research & Development Dept.
Combustion Engineering Co.

WITHIN recent years a new, powerful analytical tool has become available to industrial research and control chemists and metallurgists, namely, the X-ray diffraction technique. This method of examining materials should not be confused with the procedure which uses X-rays to obtain radiographs of welds and castings, and which the dental and medical professions use extensively to study anatomical structures. Where the radiographic technique is concerned solely with the gross aspect of substances, diffraction reveals the ultimate structure, that is, the arrangement in space of the atoms or molecules comprising the body.

Until a few years ago, X-ray diffraction apparatus was found only in a few university and industrial laboratories engaged in fundamental research. The apparatus was homemade, crude, temperamental, and incredibly long exposures were required to obtain an impression on the photographic film. Today compact, streamlined, efficient units are available. Danger from shock and exposure to stray radiation is nil. All that is needed to place a unit into operation is a source of cold water for cooling the X-ray tube and a 110-volt outlet.

One point should be made emphatic at this time. Although much has been done by the manufacturers of diffraction equipment to make it foolproof and relatively simple to operate, in so far as a laboratory technician can be trained to make diffraction patterns in a short time, the *interpretation* of the results and *deductions* therefrom can be made intelligently only by a man who has been trained in such work. X-ray diffraction analysis is a highly specialized subject embodying certain aspects of atomic physics, the chemistry of the solid state of matter and crystallography. One may draw an analogy to the X-ray and fluoroscopic examination made by a physician. Non-medical personnel can be trained to make a shadowgraph of any part of the body but only one trained in anatomy, physiology, pathology and other phases of medical science can interpret the plate and render a diagnosis. Therefore, when purchase of diffraction equipment is contemplated, consideration must be given adequate personnel to interpret the results.

An X-ray diffraction pattern may be likened to a fingerprint. Each crystalline substance diffracts X-rays differently from any other crystalline substance, and produces a unique pattern of that substance. The criteria of these differences are the distance of the lines or the spots (depending upon the technique used) on the film from a reference point, and the relative density of the lines. This is illustrated in Fig. 1 which shows the diffraction patterns of powdered samples of aluminum, lead sulfide and sodium chloride. Note how the distances from the central spot and the relative density of the lines differ.

Broadly speaking, X-ray diffraction may be used in two ways to study a chemical problem. It can be used to identify a substance or mixture of substances by comparison of the diffraction data of the unknown with the published data on several thousand compounds which are readily available (1).[1] In those cases where X-ray diffraction data on a substance are not available, certain diffraction techniques, in conjunction with a chemical analysis of the substance, make it possible to identify it.

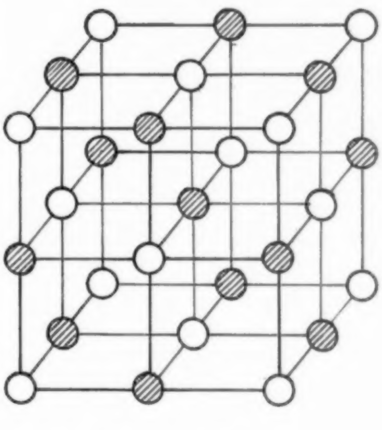
The following are a few examples of the wide variety of industrial problems which may be studied by means of the X-ray diffraction technique:

[1] Numbers in parentheses refer to references at end of article.

Fig. 1—Powder diffraction patterns illustrating difference in spacing of lines and their relative intensities of three substances. (Made by writer with filtered radiation from cobalt target)

WATER TREATMENT

(*a*) The identification of the solid phases formed on or deposited on evaporative surfaces as the result of insufficient or unsuitable chemical treatment of the water. A complete history of conditions within the boiler over a period of time may be deduced by X-ray patterns of the various layers found in a scale.



Na. ○ Cl. ◎

Fig. 2—Unit cell of sodium chloride

(*b*) The identification of deposits in superheaters and on turbine blades which formed as the result of carryover from the boiler.

(*c*) The identification of deposits and scales from softener tanks, feedlines and pumps, evaporators, economizers and air preheaters.

METALLURGY

(*a*) The composition and crystal structure of alloys.

(*b*) The effects of various heat treatments on metals and alloys with particular reference to recrystallization temperatures, stress relief, precipitation hardening and grain size.

(*c*) The effects of mechanical work on metals and alloys with respect to grain size and orientation, and internal strain.

(*d*) The identification of deposits and scale on metals as the result of corrosion by liquids or by gases at high temperatures.

The question may be raised, "Why use X-ray diffraction methods for the identification of crystalline solids when a combination of chemical and petrographic methods will yield a complete picture of their constitution?" First of all, X-ray diffraction analyses should only be considered as a complement to the other methods of analysis as it is not always possible to obtain all of the information that is desired from an X-ray pattern alone. A chemical analysis facilitates interpretation of the X-ray pattern by narrowing the *possible* compound or compounds to certain ones. One of the main advantages of X-ray diffraction analysis lies in the fact that it is a non-destructive method that determines exactly the manner in which the elements are combined, that is, the compounds which are present. In the ordinary quantitative chemical analysis the material is broken down completely by fusion with fluxes and treatment with acids and then the elements are determined separately. One then must assume, by hypothetical combinations of the elements, the original compounds that were present and this becomes practically impossible when several compounds occur in the same substance. Excellent examples of these difficulties are cited by Miller et al. (2–8). Petrographic methods of examination, performed by one skilled in this form of analysis, will identify the compounds present in a complex substance provided the individual crystals are not opaque and are large enough to be resolved under the microscope so that their optical constants may be determined. Frequently, particularly in the case of boiler deposits, the petrographic method cannot be used for these reasons, and the X-ray diffraction method is the final arbiter.

The X-ray diffraction technique suffers from none of these objections and will, if the substance has a definite crystal structure, determine with absolute certainty the phases which are present in a solid material.

In order better to understand the basic theory of X-ray diffraction a discussion of the nature of crystalline solids is desirable at this point.

Elements of Crystallography

A solid, as differentiated from liquids and gases, is a form of matter which possesses rigidity and tends to retain its shape and volume. There are two basic forms of solids, the *amorphous* and *crystalline*. In a broad sense an amorphous solid is characterized by a lack of regularity of external form. Glass, pitch and resins are typical examples of amorphous solids. A crystalline solid always exhibits some definite, regular external form such as a cube, rhomb, hexagon, pyramid or a complicated modification of these basic forms. Truly amorphous materials do not diffract X-rays, for reasons which will be clear later; therefore the present discussion will refer only to crystals.

Dana and Hurlbut (9) define a crystal concisely as "a homogeneous body bounded by smooth plane surfaces that are the external expression of an orderly internal atomic arrangement." This definition implies that the external form of a crystal is directly related to the internal arrangement of the ions, atoms or molecules comprising the solid. Many years before X-ray diffraction provided proof of this concept, crystallographers deduced from various physical and optical properties of crystals that the internal structure of crystals was orderly, that is, the unit particles from which the crystal was built was arranged in a definite geometric pattern and not in a random fashion such as occurs in gases, liquids and amorphous solids.

If ordinary salt, NaCl, is carefully crystallized from a solution, well-defined cubic crystals will result. If it were possible to crush a single crystal to the smallest possible particle which retained all of the properties of the original crystal, the arrangement of the sodium and the chloride ions in that ultimate particle would be as shown in Fig. 2. Note that the sodium and the chloride ions alternate in space and if a line is drawn through the rows of atoms a cube is delineated. This figure is only schematic, for if it were possible to see the individual atoms, they would not be rigid spheres and would probably be in quite close contact.

The cube shown constitutes the *unit cell* of the crystal. If it were to be repeated many million times in three dimensions the original crystal would result. In the case of sodium chloride it would require about 8000 trillion of these unit cells to make a cube one centimeter long on each edge. The fundamental importance of the unit cell lies in the fact that in every crystalline substance the dimensions and the arrangement of atoms constituting the unit cell are different, and X-ray diffrac-

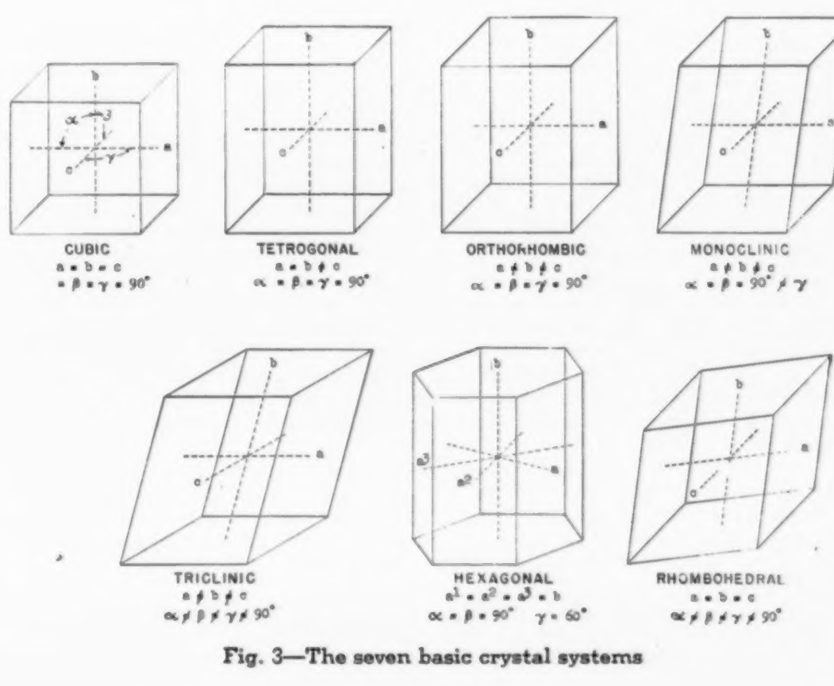


Fig. 3—The seven basic crystal systems

tion uniquely determines these factors thereby affording means of identifying an unknown crystal.

The External Form of Crystals

With regard to the external form of crystals, crystallographers classify them into seven basic geometric systems which are based upon measurements of the relative lengths of the edges and the angles that corresponding faces make with each other. These systems are referred to a set of coordinate axes as shown in Fig. 3.

ratios. Now if any non-parallel faces of the crystal are laid off on the same axes, it will be found that their intercepts on the respective axes bear a simple relation to the intercepts of the unit plane, being reducible to the parameters of the unit plane, multiplied or divided by small whole numbers. For example, assume another plane present in the crystal which cuts the axes at $^1/_2\, a$, $1\, b$, $^3/_4\, c$. Its intercepts can be expressed as integral multiples of those of the unit plane, or 2,4,3, which are the indices of the plane in question.

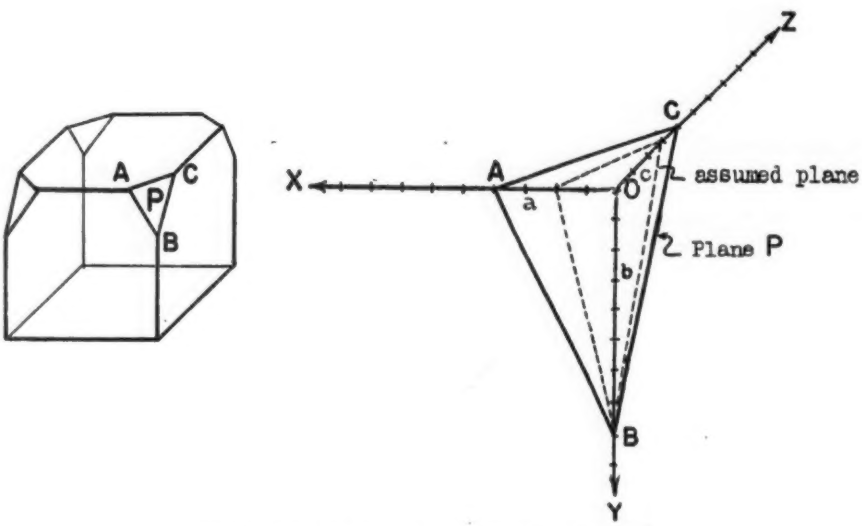


Fig. 4—Illustrating law of Rational Indices

There are numerous variations of these systems which may be developed by truncating edges and corners of the basic systems as, for example, the octahedron formed by truncating the eight corners of a cube in a symmetrical manner. Regardless of how distorted the resulting solid may appear after several of these operations, it will be found that two fundamental crystallographic laws are followed, namely, the "Law of Constancy of Interfacial Angles" and the "Law of Rational Indices." The first is based upon the fact that regardless of the external form that a certain crystal assumes, the angles between corresponding faces is always the same. The second follows from measurements of the intercepts of the various faces on a set of crystallographic axes.

As shown in Fig. 3 the geometrical form of a crystal is best described in terms of the relative lengths of its crystallographic axes and the angles between them. A certain face or plane of the crystal is selected to serve as the *parametral* or *unit* plane—a plane which cuts all three axes being an essential requirement. For example, in Fig. 4 the plane P cutting the corner of the crystal is set up on rectangular axes. The intercepts of the sides of this plane on the x, y and z axes are $OA = a$, $OB = b$ and $OC = c$, respectively. The ratios of these intercepts, known as axial ratios, are important. By convention the intercept on the y axis is set equal to unity, therefore the axial ratios in the example given are: $a{:}b{:}c = 0.5{:}0.5{:}1$. Obviously, any other plane that is parallel to plane P would have the same axial

This illustrates the "Law of Rational Indices."

It will be noted that certain faces of the cube are parallel to one of the axes and therefore would intercept it only at infinity. Therefore, in order that all indices be expressed as integers, a system of notation known as "Miller Indices" is the most conventional one used. Each plane is described by three integers, h, k, l which are proportional to the reciprocals of the indices obtained as above. Thus, with intercepts $^1/_3\, a$, $^1/_2\, b$, $\infty\, c$ for one plane and $^2/_3\, a$, $3\, b$, $2\, c$ for another, the Miller Indices, after clearing fractions where necessary, would be (320)[2] and (923), respectively. Note then that an edge parallel to any axis becomes zero.

Another important characteristic of the external form of crystals is the existence of various kinds of symmetry. Thus, if a crystal is rotated 360 deg about a certain axis, and it presents exactly the same appearance more than once, the crystal is said to have an *axis of symmetry*. If the crystal can be divided by an imaginary plane so that one part is the mirror image of the other, the crystal is said to have a *plane of symmetry*. Also, a crystal may possess a *center of symmetry* if a line drawn through a point within it intersects the surface of the crystal at equal distances on either side. That the elements of symmetry are manifold is attested by the fact that a simple cubic crystal has a total of twenty-three elements of symmetry.

[2] The Miller Indices are not read as a whole number. In the above they would be three-two-oh and nine-two-three.

More detailed discussion of this aspect of crystals is presented in several good textbooks listed at the end of this article.

Thus far, the crystallographic features of the *external* form of crystals has been considered. Inasmuch as it has been proved that the *unit cell* of the crystal, which is bounded by the ions, atoms or molecules of the solid, possesses all of the properties of the crystal, the concepts mentioned are equally applicable to the *internal* structure of crystals.

The Internal Structure of Crystals

Two important concepts of the internal structure of crystals are the *space lattice* and *lattice planes*.

Knowledge of the type of space lattice of a crystal is of paramount importance in determining the arrangement of the atoms in the unit cell. Thus, it is not enough to know that the unit cell of a crystal is cubic, hexagonal or any of the other five types of crystal system, as it has been found that in the cubic system alone the atoms may be arranged in three different ways. For example, the unit cube may be a simple cube or it may have an atom at its center, producing the *body*-centered cube, or it may have an atom in the center of each face producing the *face*-centered cube. There are fourteen different space lattices, signifying that there are no more than fourteen ways in which the ions, atoms or groups of atoms (e.g., sulfate SO_4, carbonate CO_3, etc.) can be arranged in the unit cell.

The space lattice is considered easiest in terms of two dimensions as shown in Fig. 5 where one face of the unit cell of sodium chloride (Fig. 2) is repeated many times to produce an array of equidistant sodium and chloride ions. When this is extended in three dimensions, the resulting collection of points is called a *space lattice*.

The important criterion of the space lattice is that each ion, atom or group of atoms constituting the points of the space lattice has identical surroundings. For

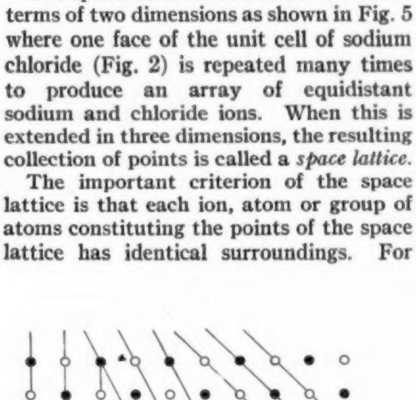


Fig. 5—Some possible lattice planes through the atoms of a two-dimensional, cubic space lattice

example, in Fig. 2 each sodium ion has four chloride ions and each chloride ion has four sodium ions, as nearest neighbors. It will be noted that the sodium chloride lattice is a face-centered cube.

With regard to the *lattice planes*, Fig. 5 shows that the lattice points may be arranged in certain rows as shown by the parallel lines drawn through them. In three dimensions, these parallel lines constitute the lattice planes of the crystal. A familiar analogy may be drawn from what one sees when driving past a regularly planted field of corn—at certain points well-defined rows of corn will be seen.

It should be noted that certain planes will be more densely populated with atoms

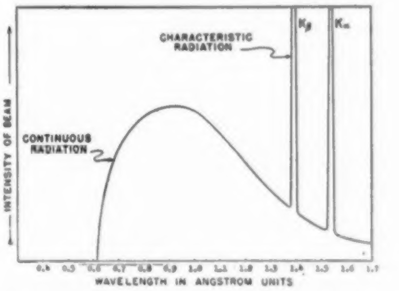


Fig. 6—Variation of intensity of radiation from a copper target at 20,000 volts

than others (cf. $A_1A_2A_3$ with $B_1B_2B_3$) and that the planes will contain either all one kind of atom or both kinds, this of course depending upon the substance as it is obvious that in the elements the atoms are all the same.

The Generation and Properties of X-Rays

In 1895 Wilhelm Roentgen was experimenting with an evacuated tube containing two electrodes charged to a high potential difference. Some time earlier Sir William Crookes had demonstrated that the negatively charged electrode (cathode) of such a tube produced a stream of electrons which traveled toward the positive electrode (anode). Roentgen had been using crystals of barium platinocyanide to detect radiation from the tube of wave length too short to affect the eye. This salt glows (fluoresces) when exposed to ultra-violet, or light of shorter wave length. He noted that the crystals fluoresced strongly when the tube was completely covered with opaque paper. It was evident that some new kind of radiation, capable of penetrating solid, opaque matter was emanating from the tube and he called it "X-rays," a name indicating the then unknown character of the radiation.

These rays resemble visible light in many respects. They radiate in straight lines from their source, darken photographic paper, cast sharp shadows, and can be refracted, diffracted or polarized. Other important characteristics are that they can penetrate solids, ionize gases and cause fluorescence of certain salts.

The explanation of Roentgen's observation lies in the fact that when high-speed electrons, the speed of which is proportional to the voltage at which they are generated, are stopped abruptly by solids, X-rays are produced. Thus the electrons in the evacuated tubes, impinging on the glass walls of the tube and the metal anode, produced X-rays which penetrated the tube walls and paper shield and caused the barium salt to emit light.

Similar to light, X-rays are electromagnetic waves. The only difference between the two is the magnitude of the wave length, X-rays being much shorter. The unit of wave length is the *Angstrom* which is equal to 10^{-8} cm (= 0.003937 millionths of an inch). For comparison, the spectral range of visible light is about 3800–7500 A while that of X-rays is 0.1–1000; the useful range for most diffraction work being 0.56–2.29 A.

As stated, X-rays are generated when electrons moving at a high velocity are suddenly stopped by a solid material. If the voltage producing the electrons is high enough and the anode, or target, which they strike is a suitable material, two kinds of X-ray radiation are produced. These are known as *continuous radiation*, or radiation of a single definite wave length. The following example illustrates the manner in which these types of radiation are obtained.

If a copper electrode is placed close to a heated tungsten filament within an evacuated tube and the copper is charged positively with respect to the filament, electrons traveling from the filament bombard the copper and produce X-rays. With a potential difference between the copper cathode and the anode (filament) of 20,000 volts, and suitable apparatus for measuring the intensity of radiation at various wave lengths, one would obtain a curve like that shown in Fig. 6. Two important characteristics of this curve for a copper target are:

(*1*) There is a broad range of wave lengths extending from 0.617 A as the shortest wave length, to an indefinite long wave length. This is the *continuous* spectrum emitted by the tube, and it has a maximum intensity of approximately 1.5 times the shortest wave length, or 0.92 A.

(2) There are two very sharp peaks in the intensity at wave lengths 1.39 A and 1.54 A. These are the *characteristic* radiations from a copper target.

The minimum wave length of the continuous radiation depends only upon the voltage applied to the tube, and may be calculated from the relation

$$\lambda = \frac{12340}{V}$$

where

λ = minimum wave length in Angstroms

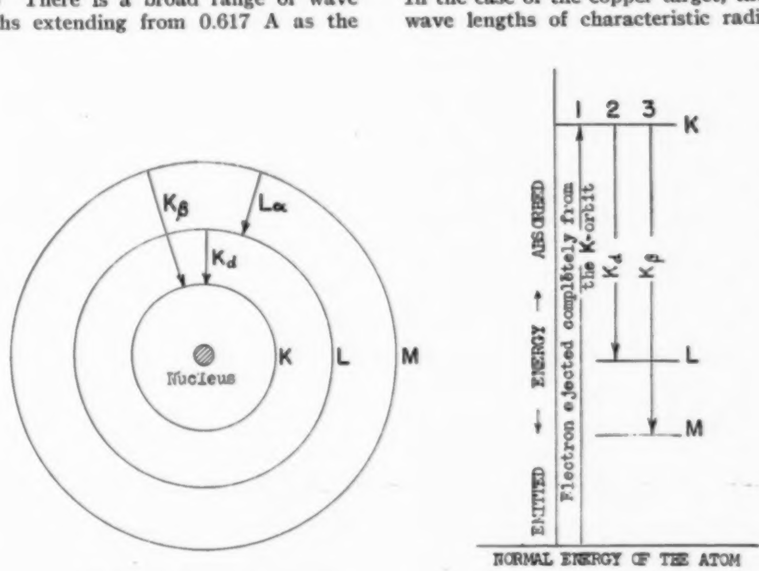
V = voltage difference between the target and the filament

Thus, if the voltage were to be increased to 30,000 volts, the minimum wave length would decrease to 0.41 A and the maximum intensity would occur at 0.62 A; that is, with increasing voltage the minimum wave length and the wave length of the strongest beam of the continuous radiation both become shorter. The *continuous* radiation is utilized by the radiographer in X-raying anatomical structures, castings, etc., and the targets and voltages are selected to obtain the optimum penetrating power for the object being studied.

The *characteristic* radiation is of primary importance to the X-ray diffraction technique as it constitutes a source of monochromatic radiation, that is, radiation of a specific wave length. The importance of this will become evident in the discussion of the diffraction of X-rays by crystals.

Characteristic radiation is produced only when the voltage on the tube is raised above a certain critical value that depends upon the material used for a target. In the case of the copper target, the two wave lengths of characteristic radiation shown in Fig. 6 would not appear if the tube had been operated at less than about 9000 volts. The wave length of the characteristic radiation from any one kind of target does not change, as does the continuous radiation, with an increase of voltage.

Although the mechanism of the genera-



(a) Some of the electronic orbits in an atom

(b) The energy levels of the orbits

Fig. 7—Bohr's concept of the electronic orbits in an atom and the manner in which energy is radiated when an electron is knocked out of the K-orbit of the atom

tion of characteristic radiation is an involved subject of atomic physics, the following simple concept is sufficiently accurate to provide an understanding of the processes involved.

Each atom of matter is considered to consist of a positively charged nucleus about which negatively charged electrons revolve in various orbits. A normal atom is electrically neutral; therefore, the number of electrons must balance the positive charge on the nucleus. The charge on the nucleus is different for each element; hence each has a different number of electrons. For example, the hydrogen atom, which is the simplest of all atoms, has one electron, while an element like copper has 29 electrons rotating about the nucleus. The orbits in which these electrons revolve are designated as *K*, *L*, *M*, etc.; the *K*-orbit lying closest to the nucleus as shown schematically in Fig. 7 (*a*).

The significant features of atomic theory that are pertinent to the present discussion are as follows:

(*a*) The maximum number of electrons that an orbit may contain is fixed; e.g., the *K*-, *L*- and *M*-orbits can have no more than 2, 8 or 18 electrons, respectively.

(*b*) An electron will remain indefinitely in its orbit unless it is disturbed by some external force of energy greater than that possessed by the electron.

(*c*) Energy is absorbed if an electron moves from an inner to an outer orbit, and is emitted if it moves from an outer to an inner orbit. This is shown schematically in Fig. 7 (*b*). For example, if an electron from the *K*-orbit is ejected completely from the atom, the atom will absorb energy shown by arrow *1*. Then if an electron moves from the *L*-orbit to replace the ejected electron, the energy emitted by the atom in the form of X-ray radiation will be equal to the difference in energy between the two orbits, as shown by arrow *2*. This is called the $K\alpha$ emission, which in the case of copper, as shown by the second peak in Fig. 6 has a wave length of 1.539 A.[3] When the electron moves from the M-orbit to the K-orbit the difference in energy is greater, consequently the wave length of the radiation emitted is shorter. In the case of copper it is 1.39 A and is called $K\beta$ line. Similarly, if an electron is knocked out by the *L*-orbit and is replaced by one from the *M*-, *N*- or *O*-orbit, the *L*-series of monochromatic radiation is produced.

(*d*) The energy required to effect these changes in the atom may come either from an electron, as has been described, or it may come from X-rays; that is, X-rays of sufficiently high energy can eject electrons from an atom as well as high-velocity electrons. This is an important factor in relation to the prevention of fogging of the film in an X-ray camera. Without going into the details of this phenomenon, it suffices to mention that if a sample containing a high percentage of iron is being studied, radiation from either an iron target or some element preceding iron in the periodic system should be used. Radiation from a copper target, which has a higher energy than the *K*-orbit of an iron atom, would cause the iron atoms in the specimen to emit X-rays in all directions in the camera which would fog the film.

The target metals most used for diffraction analysis are chromium, iron, cobalt, nickel, copper or molybdenum; the choice depending upon the wave length that is desired and the type of material that is being studied. For most purposes, use is made only of the $K\alpha$ radiation from the tubes as it is the most intense beam. The other characteristic rays, such as $K\beta$, $L\alpha$, etc., which are generated simultaneously, are absorbed by special screens through which the X-rays pass before reaching the specimen.

[3] Energy is related to wave length by the equation $e = hc/\lambda$, where e = energy, h = a constant, c = velocity of light and λ = wave length.

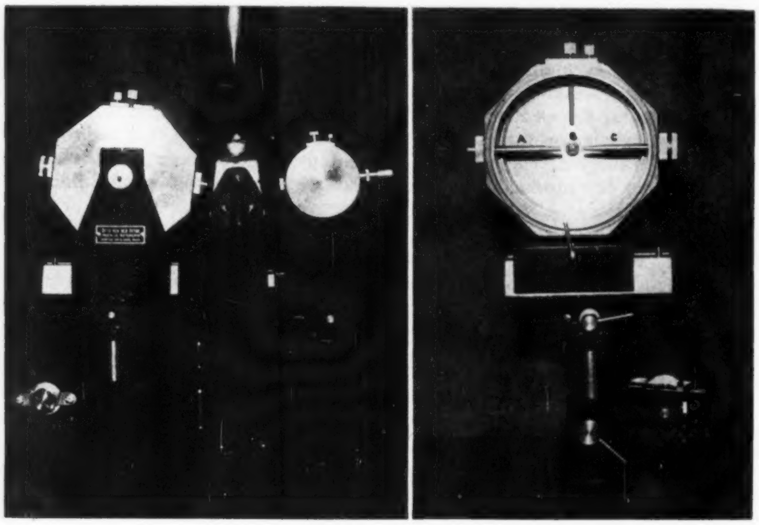


Fig. 8 (*a*)—A 57.3-mm and a 114.6-mm powder camera in operating position before a filament-type X-ray tube Fig. 8 (*b*)—The 114.6-mm camera with cover off to show (*A*) pinhole system for collimating the beam, (*B*) the specimen mount, (*C*) the exit tube for undiffracted beam, and (*D*) the fluorescent screen for aligning the specimen and beam

These photographs were taken by the author through the courtesy of Dr. S. S. Sidhu, of the Physics Department, University of Pittsburgh

The following table shows the wave length of the $K\alpha$ radiation from various targets and the operating voltages.

TABLE 1

Target	Wave Length of *K* Radiation (A)	Minimum Voltage to produce *K* (Kv)	Maximum Operating Voltage of Tube (Kv)
Chromium	2.287	6	35
Iron	1.934	7	40
Cobalt	1.787	8	45
Nickel	1.655	8.5	50
Copper	1.539	9	50
Molybdenum	0.709	20	80

In order to obtain sufficient intensity of the $K\alpha$ radiation, it is to be noted that the operating voltage is considerably higher than the minimum voltage to produce this radiation. The voltage is limited, however, by the amount of heat that can be dissipated by the target to the cooling water, for if the voltage should be too high the target would be damaged by overheating. Failure of the cooling-water supply to a tube can cause a copper target to melt in a few minutes.

There are two general types of tubes used for diffraction work. One type is known as the "gas" or "cold" tube which contains a target and a cathode in a glass envelope which is pumped down to a low pressure, this pressure being maintained by balancing the rate of pumping against a controlled leak of air to the tube. The small amount of residual air in the tube is ionized by the potential across the tube. These ions are attracted to the cathode and bombard it with sufficient energy to eject electrons which then travel to the target and produce X-rays. The other type is the "electron" or "hot" tube which contains a hot filament as the source of electrons. This type is highly evacuated, residual gases being deleterious, and usually is sealed off during manufacture. Fig. 8 (*a*) shows a commercially available tube of this type in operation with two cameras in position. It has two sealed-in windows of beryllium metal through which the X-rays pass with greater ease than through glass.

Diffraction of X-Rays by Crystalline Materials

The basis for the diffraction of X-rays by a crystal is best discussed from the standpoint of the behavior of visible light under conditions with which the reader is most familiar. As in the discussion of the internal structure of crystals, two-dimensional analogies will be used.

It will be recalled from elementary physics that although light is considered to travel in straight lines, under certain conditions it appears to bend around the edges of an obstruction in its path. Thus, if a beam of monochromatic light passes through a very narrow slit or a pinhole, the image produced on a screen is larger than the opening in either of the obstacles and is seen to have a diffuse border consisting of alternating light and dark bands. Thus, in effect, the light has bent somewhat around the edges of the opening. This bending of light is known as *diffraction*, and is responsible for many optical phenomena.

As the opening is made smaller and smaller it will be found that the emergent light beam begins to diverge. As long as

the opening is relatively large the hazy edge of the beam is imperceptible but as the dimension of the opening becomes of the order of the wave length of the light, the diffracted region of the beam begins to predominate over the main part of the beam. If the opening should be two wave lengths wide, the light will diverge as a 30-deg cone, and if it is less than half a wave length, it will spread nearly uniformly in all directions. Under these conditions the opening may be considered to behave as a point source of spherical wavelets which, because they spread out at a wide angle, give the effect of the light bending around a sharp corner.

The essential condition for producing large diffraction effects is that the size of the opening through which the light rays must pass be of the same order of magnitude as the wave length of light. Carrying the single slit to the case where there are a number of such slits, equally spaced along a straight line as shown in Fig. 9 (*a*), it will be noted that each slit is a source of wavelets. Where the emergent rays are "in phase," that is, when the crests and troughs coincide, a reinforced beam results, each slit contributing some of the light. Where the rays are "out of phase," they annul each other and no image is produced. Alternate light and dark bands would be seen on the screen shown in Fig. 9 (*b*). The position of the bands would shift with changes in the wave length of the light and the distance, *d*, between the slits. The important fact to note from these figures is that reinforcement of the waves occurs only when the difference in path traveled by the waves from succeeding slits differs by *one wave length or any multiple thereof*, that is, by $n\lambda$, where n is a whole number. This is determined by the wave length of the light and the distance between the slits.

In experimental physics the effect of equally spaced slits is obtained by engraving thousands of parallel lines per inch on a glass plate. This is known as a *diffraction grating*, an instrument that is indispensable to the spectroscopist.

For some time after Roentgen discovered X-rays, it had been suspected that they had the same wave character as light and therefore should exhibit diffraction and interference phenomena. Although many experiments had been made to diffract X-rays, the results were not conclusive. In 1912 it occurred to Laue that a crystal might behave as a natural diffraction grating with the unique advantage that the spacing between the rows of atoms was many times smaller than any that had been made, and probably of the same order of magnitude as the wave length of X-rays. Experiments were conducted accordingly by Friedrich and Knipping and the effects which were predicted by Laue's theory were found. Thus was laid the foundation for the science of X-ray diffraction.

The Laue theory is difficult to grasp as one must visualize in three dimensions, the two-dimensional conception of the grating described above. However, W. L. Bragg clarified the picture considerably by considering the diffraction in terms of "reflection" from the lattice planes of the crystals in the following manner:

Referring to Fig. 10, the two atomic planes in a crystal consist of densely populated planes of atoms, such as are shown in Fig. 5. Suppose that a parallel, monochromatic beam of X-rays strikes atoms at A and B, at an angle θ to the planes, causing them to behave essentially as point sources of new wavelets. Although these wavelets are scattered in all directions, Bragg regarded the planes of atoms as reflecting the incident beam, in which case the angle of *reflection* would equal the angle of *incidence*. The successive planes parallel to the ones shown each would "reflect" a portion of the beam at angle θ resulting in a series of waves in the direction of AR_1. However, for reinforcement of these waves from these planes to occur, the path difference between them must be one wave length or a multiple of it. The conditions necessary for this in the present case are shown in the figure. Thus, the path traveled by the lower wave lags behind the upper by the distance $CB + BD$ and as this is equal to one wave length (it might have been $n\lambda$, where n is any whole number) one obtains after constructing the perpendiculars AB and AD.

$$CB + BD = n\lambda = 2d \sin \theta$$

where

d = distance between the atomic planes
θ = angle of incidence of X-ray beam to atomic planes
n = number of whole wave lengths that reflection from successive planes lags behind

This is the Bragg equation. It is the fundamental equation that is used universally in all X-ray diffraction work.

For most identification studies, radiation of a single wave length is used; generally the $K\alpha$ radiation from a particular target. Therefore, knowing the wave length and measuring the angles of the diffracted beams, it is possible to determine the spacing, *d*, between the planes in crystals. Fig. 11 illustrates the effect of various wave lengths upon the diffraction angles of aluminum. Note that for a given line, the distance from the central spot becomes larger with radiation of longer wave length. Conversely, one may determine the wave length of X-rays by using a crystal whose *d* value is known precisely, and measuring the diffraction angles.

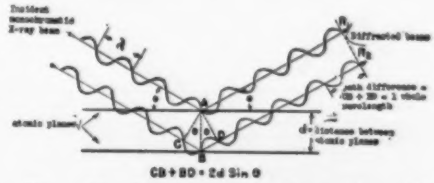


Fig. 10—Showing relation of path difference of waves to distance between atomic planes and the angle of the incident beam in accordance with Bragg's law

Before discussing the methods of diffraction analysis, it is necessary to mention that in addition to measurements of the diffraction angles of a crystal, it is also necessary to measure the *relative* intensity of the lines. The *d* values and the relative intensity of the lines corresponding to them have unique values for every crystalline substance.

The differences in intensities may be explained briefly by reference to Fig. 5. The "reflection" taking place from planes $A_1A_2A_3$ would be stronger than from planes $B_1B_2B_3$ because the former are more densely populated with atoms. Another factor which affects the intensity of "reflection" from a plane is the kind of atom which it contains, as all atoms do not diffract X-rays alike. The ability of an atom to diffract X-rays is related to the number of electrons traveling about the nucleus; the larger the number of electrons, the greater will be the intensity of diffraction.

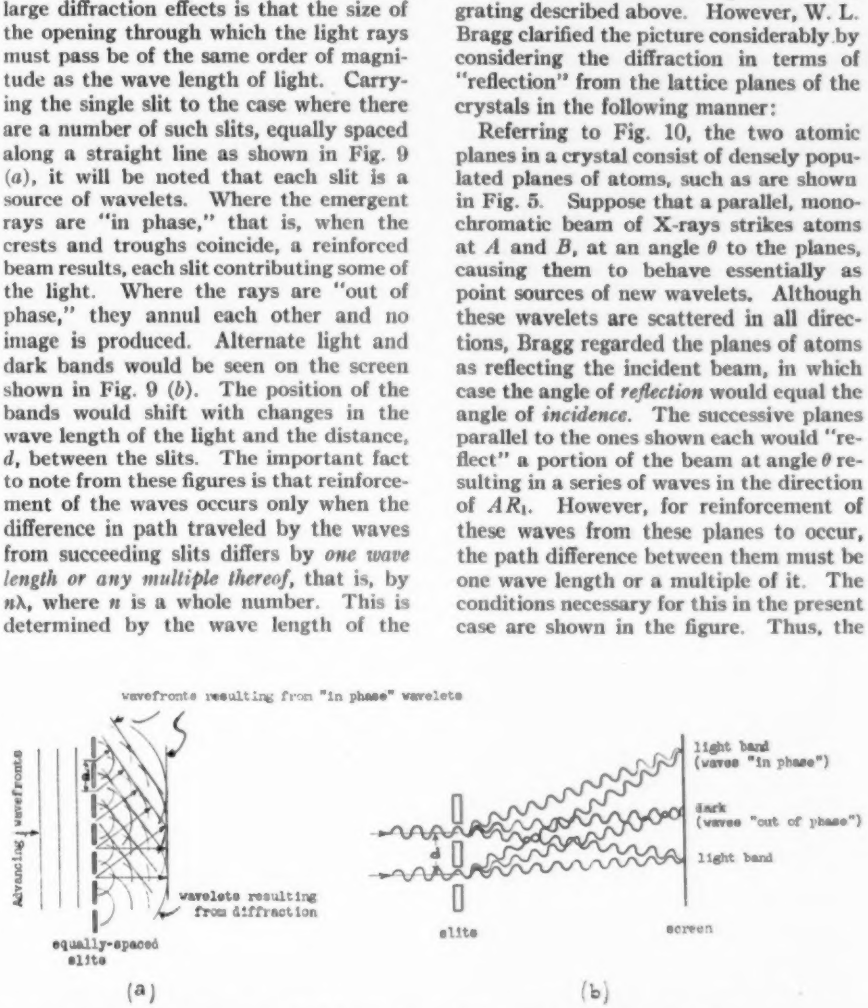


Fig. 9—The diffraction of light at slits: (*a*) showing diffracted beams from a number of equally spaced slits reinforcing each other at a definite angle; and (*b*) details of occurrences at two of the slits showing that when the defracted waves are "in phase" reinforcement occurs, and when they are "out of phase" they annul each other

Methods and Apparatus

There are three general methods of studying crystals by means of X-rays, namely, (*a*) the Laue method in which a stationary single crystal is exposed to continuous radiation, (*b*) the rotating-crystal method in which a single crystal is rotated or oscillated in a beam of monochromatic X-rays, and (*c*) the powder method in which the specimen is ground to a fine powder and radiated with monochromatic X-rays.

The first two methods are used primarily for fundamental studies of crystal structure and in metallurgical work for studying grain size and orientation, recrystal-

lization and distortion. The powder method is extremely versatile but finds its greatest use in the identification of compounds in an unknown sample. Inasmuch as the technical personnel to whom this article is addressed would be most interested in this phase of diffraction analysis, the powder technique will be discussed briefly.

The Powder Method

This method was developed independently by Debye and Scherrer in Germany and by Hull in this country. A monochromatic X-ray beam is allowed to fall on a specimen of the substance that has been ground to about 250-mesh. This is shown schematically in Fig. 12. Due to the randomness of orientation of the crystals, a certain percentage of the particles will lie with a given set of lattice planes at the correct angle to the incident beam to produce a "reflection" at a definite angle in accordance with the Bragg law. Another percentage of the particles will lie with a different set of planes oriented so as to produce "reflection" at another angle, and so on until every set of planes in the substance that will produce reflection is accounted for. In effect, it is as though one were to rotate a single crystal of the substance in an infinite number of directions in the X-ray beam.

The "reflected" rays generate a cone with the specimen at the apex. The most general method for recording the reflections is to bend a narrow strip of photographic film circularly around the specimen, the axis of the specimen being located at the center. If a pinhole is used to collimate the X-ray beam, the lines produced on the film by intersection of the reflected cones are concentric rings which become straight at an angle of 90 deg to the main X-ray beam, and begin to curve in the opposite direction at larger angles. This effect is seen in Figs. 1 and 11. If the beam is collimated by a slit, the lines are straight. The cameras shown in Figs. 8 (*a*) and 8 (*b*) are typical of those used for powder work. Generally they are fitted with a small synchronous motor which rotates the specimen slowly so that the greatest number of particles are exposed to the X-ray beam. A hole is cut in the center of the film to permit the undiffracted portion of the X-ray beam to pass out of the camera, for if this were not done, severe fogging of the film would occur.

There are several ways of mounting the powdered specimen in the camera. In one method, the powder is packed into a thin-walled capillary tube of about 0.5 mm diameter. The tube may be cellophane, celluloid or a borosilicate glass—these materials being amorphous, they do not produce lines on the film. Another method consists of coating a fine fiber with a thin paste of the sample and collodion. A method that is widely used consists of making a thick paste of the powder with collodion, tamping this into a stainless steel capillary tube that is about 0.6 mm I.D., and then extruding it partly so that about 3 mm project beyond the end of the steel tube, the latter serving as a mount. Another favored method is to pack the powder into a special holder that makes the specimen wedge-shaped and to place it in the camera so that it cuts across a slit-collimated beam.

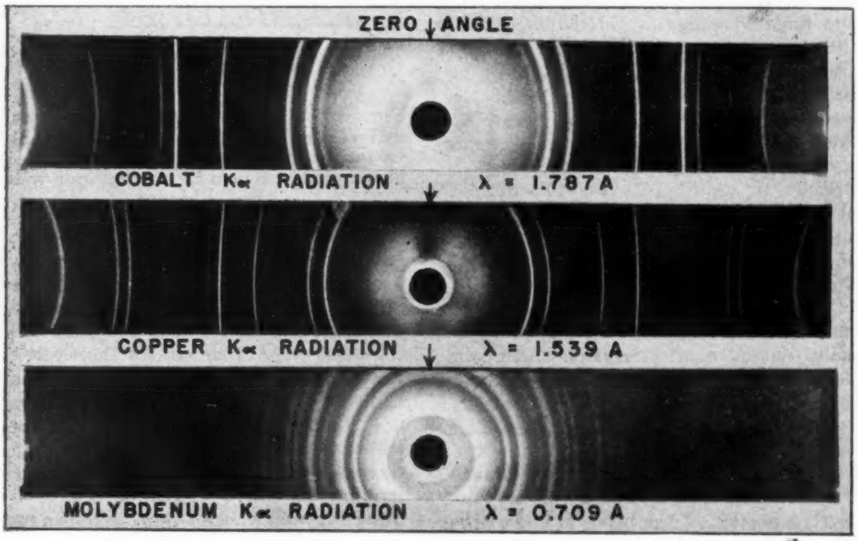


Fig. 11—Powder patterns of aluminum made with different targets to illustrate effect of various wavelengths on Bragg angles in accordance with the relation, $\gamma = 2d \sin \theta$

The ultimate purpose of an analysis of this kind is to obtain the *d* values of the lines produced by reflection from various atomic planes in the crystal. With Bragg's law as the basis, the calculations are made from the films in the following manner:

Referring to Fig. 12, one-half of the angle of the cone generated is $2\,\theta$ where θ is the angle the X-ray beam makes with the atomic planes in question. As there is a corresponding line below, the total angle is $4\,\theta$. The film is laid flat and the distance *s* is measured accurately; the diameter of the specimen being subtracted to give s'. The angle θ that occurs in Bragg's law is obtained by

$$\frac{s'}{4r} \text{ radians} \times 57.3 \frac{\text{degrees}}{\text{radian}} = (\text{degrees})$$

where r = distance from specimen to film.

Then knowing the wave length of the radiation that is used (see Table 1) the *d* values of the planes at which reflection occurred follows from Bragg's law:

$$d = \frac{\lambda}{2 \sin \theta}$$

The *d* value and the relative intensity of each set of lines is recorded. If the substance is a single compound its identification is relatively simple. Collected data on several thousand compounds are available, and usually all that is needed is to compare the *d* and the relative intensity values of the three strongest lines in the pattern with the reference data; a special system of indexing the reference data making it possible to watch the unknown quite rapidly. If the substance contains several compounds the problem is more difficult, but if data are available for all of them, it can be done in a few hours. If a chemical analysis of the material has been made, the identification of a mixture of several compounds is facilitated.

Conclusion

X-ray diffraction theory and practice are subjects of broad scope and only the barest details have been presented in this article. It is hoped, however, that sufficient background has been derived by the reader to afford a better understanding of the purpose of X-ray diffraction and to appreciate the unique value that it has to certain types of research and control work. Many industrial laboratories engaged in problems related to the generation and utilization of steam have installed diffraction equipment in recent years and there is no question that the investment has been repaid many times over both in hours saved in laborious quantitative chemical analyses and in the satisfaction of being able to identify unequivocally the compounds that are present in an unknown material.

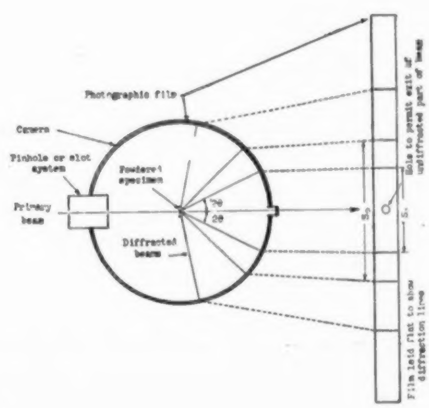


Fig. 12—Method for obtaining diffraction pattern of powdered materials by employment of the Debye-Scherrer-Hull technique

For more details of theory and practice, the reader is referred to the list of a number of excellent texts that have been published in recent years.

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BOOKS AND ARTICLES OF GENERAL INTEREST

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*"X-Rays in Research and Industry," Hirst, Chemical Publishing Co., 1943.

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*"A.S.T.M. Symposium on Radiography and X-Ray Diffraction Methods," 1936.

"Symposium on X-Ray Analysis in Industry," *Journal of Scientific Instruments*, **18**, May and July 1941.

"X-Ray Physics and X-Ray Tubes," V. Hicks, *Journal of Applied Physics*, **12**, 364 (1941).

* These texts are quite simply written and provide an excellent general background to the subject. The others are more suited to the advanced student.

Coal Stocks Increase

The seasonally decreased use of bituminous coal for heating during May permitted a halt in the depletion of stocks for the first time in ten months. According to the Solid Fuels Administration, the maintenance of heavy mine output in May, with the aid of newly developed strip mines and high midwestern production brought bituminous stockpiles in consumers' hands up to 55,307,000 tons as compared with 50,513,000 tons on May 1. However, the stockpiles are still far short of the 79,525,000 tons held on June 1, 1943. Stocks held by various classes of consumers in terms of days supply, as of June 1, 1944 were as follows:

Electric utilities	83
By-product coke ovens	23
Steel and rolling mills	28
Coal gas retorts	50
Cement mills	51
Other industries	51
Railroads	34
Retail dealers	19

Notwithstanding the above, the coal stocks of electric utilities as of June 1, 1944, were 1919 per cent under those of the same date last year.

Bituminous coal mined during the calendar year 1944 through June 24 amounted to 309,030,000 tons as against 279,122,000 tons produced in the corresponding period of 1943. Anthracite production for the same period this year was 32,051,000 tons.

Hydro Policies Proposed by Chamber of Commerce

The U. S. Chamber of Commerce has put forward a program of natural water resources policies emphasizing the rights of states in the development of water powers and advocating the preservation of private enterprise in such development. It notes that not only the accelerated development of water resources in recent years, but also the extensive plans for the continuation of such development when the war ends, make imperative a clarification of Federal policy in these respects. The declarations of policy cover the following points:

1. That legislative policy afford full opportunity for private enterprise, both to participate in such development and to purchase and use or resell products, including power, that result from water use and control projects developed by the government.

2. That any government sale of products, which are also manufactured and sold by citizens, should be at prices sufficient to cover all costs and the same burden of taxes as are paid by citizens. This pricing should apply regardless of whether Congress specifies preference or priority in sales to municipalities, cooperatives or other publicly owned agencies.

3. That Congress regain control of the development of water resources which it has lost to administrative agencies, and perfect its authority over future public works.

4. That all projects under consideration be re-estimated in the light of greatly increased construction cost levels.

5. That no project be undertaken without careful consideration of its relation to other projects and its effect on other lines of endeavor.

6. That all hydro power developed, whether by public or private agencies, should participate in regional power pools in order to realize the maximum benefits possible in combination with other sources of power.

7. A program of development is favored wherein the purpose of each project, especially multi-purpose projects, are clear and declared in advance and cannot be lost subsequently through diversions and changes.

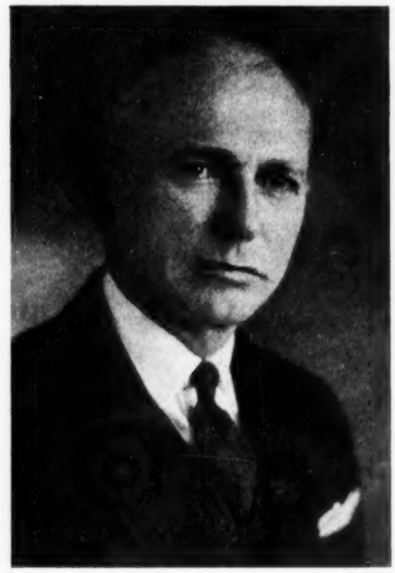
8. That in the exercise of jurisdiction over rivers, Congress recognize the interests and rights of the states in water utilization and control, and limit the authorization and construction of navigation works and improvements to those which can be operated consistently with the fullest use of such rivers for all purposes. The "commerce clause" should not be used to limit water uses as established by the states; and where more than one state on the same stream is involved the division of water should be made by interstate compact, where possible.

9. That every Regional Authority plan be examined with great care because of the serious and obvious social and political problems involved.

10. Finally, that the development of water resources of the nation be developed for the greatest benefit of the nation as a whole and to the people in the territory in which they are located; this to be done upon sound, constructive and forward-looking engineering and economic policies free from politics and on a nonpartisan basis.

A.S.M.E. Nominations

Nominations for the 1945 officers of the American Society of Mechanical Engineers were announced by the Nominating Committee at the conclusion of the Semi-Annual Meeting at Pittsburgh on June 22.



Alex D. Bailey

Election will be by letter ballot of the membership closing September 26, 1944. The officers nominated are as follows:

President: Alex D. Bailey, Vice President of the Commonwealth Edison Company, Chicago.

Vice Presidents: David Larkin, Vice President and General Manager of the Broderick & Bascom Rope Company, St. Louis, Mo.; John E. Lovely, Vice President of Jones & Lamson Machine Company, Springfield, Vt.; Thomas S. McEwan, Vice President of McClure, Hadden & Ortman, Inc., Chicago.

Managers: Daniel S. Ellis, Vice President of Lima Locomotive Works, Lima, Ohio; Arthur J. Kerr, Dist. Manager, Pittsburgh Equitable Meter Company, Tulsa, Okla; Herman G. Thielscher, Mechanical Engineer, Potomac Electric Power Company, Washington, D. C.

The new officers will assume their duties at the conclusion of the Annual Meeting in December.

Personals

Clarence J. Hunter has been elected President and General Manager of The Dampney Company of America, manufacturer of protective coatings for metals, succeeding the late William H. Laverack. Mr. Hunter has been associated with the Company in various capacities since 1926 and has long been identified with marine, railroad and stationary power specialty

Clarence J. Hunter

manufacture and sales. Other officers of the Dampney Company elected at the same time are **J. W. Laverack,** Vice President and Treasurer; **J. Dwight Bird,** Vice President in charge of railroad and midwest sales; and **William Richards,** Vice President in charge of marine sales.

Charles A. Powel, Manager of the Headquarters Engineering Department of Westinghouse Electric & Manufacturing Company, has been elected President of the American Institute of Electrical Engineers for the year beginning August 1, 1944.

C. B. Campbell has been made Manager of Engineering of Westinghouse Electric & Manufacturing Company, filling the position left vacant by the promotion of Floyd T. Hague to assistant to the vice president in charge of the steam division. Mr. Campbell joined the Company in 1919 as a technical apprentice, after graduation from the University of Michigan, and has served in various capacities dealing with steam turbine engineering. His new responsibilities will be concerned with naval propulsion equipment, steam turbines for land use, gas turbines, compressor and condenser equipment and certain development work.

Walter Greacen, for the past nine years a mechanical engineer with E. M. Gilbert Associates of Reading, Pa., has joined the New York State Electric & Gas Corp., Binghamton, N. Y., as mechanical consultant on power plant operations.

An Appreciation

Thirteen years of intimate association with the late Geo. A. Orrok, engineer, have been an experience of rich and lasting value. My appreciation and gratitude for those years, so full of professional inspiration and warmest friendship, can only be exceeded by my daily sense of loss in the passing of "Uncle George."

To have enjoyed this long period of closest association with an engineer of his international reputation and high and generous character, was indeed a rare privilege, and one never to be forgotten.

Much has been published regarding his professional life, and his record of extensive and versatile accomplishment. There has not been the slightest exaggeration in any of these accounts, which are a source of pride to his astonishingly large number of friends and acquaintances in the many countries of the world where his work and personality were so favorably known.

I need add nothing to all of this, but as his professional associate and close friend, I desire publicly, to express my admiration and respect for Geo. A. Orrok and to contribute these few words in honor of a great engineer, a true gentleman, and a very dear friend.

David Moffat Myers

NEW CATALOGS AND BULLETINS

Any of these publications will be sent on request

Ash Handling Equipment

Hydro-Ash Corporation has issued a 46-page typescript booklet containing more than 30 pages of drawings showing arrangements and details of its Ash Conveying Systems. These working drawings cover ash hoppers and gates, sluicing systems, fly ash and siftings conveying, and "Nu-Matic" conveyors for dry ash. Eleven typescript pages are devoted to explanatory text. This informative material is supplemented by an earlier bulletin containing many photographic illustrations of installations using this type of ash-handling equipment.

Boiler Ratio Meter

Cochrane Corporation has issued publication No. 4071 on its new Boiler Ratio Meter. This discusses methods of checking combustion efficiency and gives a detailed description of the meter, designed to meet these requirements. Installation details are included.

Fire Extinguisher Maintenance

Walter Kidde & Company has published a 12-page booklet entitled "Inspection and Maintenance of First Aid Fire Extinguishers." A basic maintenance system is outlined, including questions of supervision, record-keeping and recharging of all types of extinguishers. The booklet is illustrated with drawings, photographs and charts, and the importance of actual demonstrations in fire-fighting technique is stressed.

Flow Meters

Builders-Providence, Inc., has issued a 4-page illustrated bulletin (No. 350) featuring its "Propeloflo" meter for main line metering (2 inches or larger). This propeller type totalizing flow meter with a direct-reading six digit counter has a meter body of Venturi design. Remote location indicator and recording instruments are also described.

Heavy Duty Heaters

B. F. Sturtevant Company has issued an attractive 36-page catalog (No. 462) dealing with its line of heavy duty heaters. The design and constructional features of these finned heaters are admirably pictured and described. Engineering data given include: temperature rise constants; selection tables giving final temperature and rate of condensate; temperature charts; heater dimensions; a table of heater weights and numerous piping diagrams.

High-Temperature Insulation Standards

New production of Mineral Wool under Commercial Standard CS117-44 entitled "Mineral Wool: Blankets, Blocks, Insulating Cement, and Pipe Insulation for Heated Industrial Equipment" has been announced by the National Bureau of Standards, U. S. Department of Commerce. Formulated in cooperation with the Specification Committee of the Industrial Mineral Wool Institute, it is the first and only authoritative high-temperature insulation standard promulgated by the Bureau of Standards designed to serve the best interests of the industrial and commercial consumer.

Until CS117-44 is printed by the Government Printing Office, a 30-page mimeographed copy of the Standard will be supplied gratis by the Industrial Mineral Wool Institute, when requested on company letterhead stationary, for as long as the supply lasts.

Pyrometers

C. J. Tagliabue Mfg. Company has issued a new 38-page catalog (No. 1101H), featuring its line of TAG "Celectray" instruments for recording, indicating and controlling temperatures. The sensitivity speed and adaptability of "Celectray" photoelectrically balanced instruments are fully described and admirably pictured in its pages.

Steam Turbines

The Terry Steam Turbine Company has issued a 4-page bulletin (S-140) featuring its line of steam turbines for all applications and operating conditions from 5 hp to 2000 hp. Numerous halftones illustrate the Terry Solid Wheel Type Turbine and its applications, and also the Terry Single Stage and Multi-stage Axial Flow Turbines.

V-Belt Drives

"Texrope" Fractional Horsepower V-Belt Drives is the subject of a 44-page catalog just issued by the Allis-Chalmers Mfg. Company. This copiously illustrated booklet shows typical examples of constant or adjustable diameter sheaves and FHP V-belt installations. Horsepower rating tables, general engineering data and innumerable drive selection tables for both A and B belts are also given.

Books

1—Practical Marine Diesel Engineering

By Louis R. Ford

642 pages   6 × 9$^{1}/_{8}$ Price $6.00

The present (fourth) edition of this book has required little change in the body of the text as the diesels featured are those used in the Maritime Commission's standard motorships. Considerable space is devoted to their construction, operation and maintenance. Space is also given to descriptions of machinery arrangements in these ships, and the indirect drive system adopted by the Commission is thoroughly explained.

In the present edition two new chapters have been added: one covering Deck Machinery and the other, Electrical Machinery. These are designed to acquaint the engineer with the principal types of equipment outside the engine room that are serviced by the engine room crew. Latest developments in new types of equipment associated with motorship propulsion, such as electric couplings, hydraulic couplings, superchargers, etc., are discussed to give the engineer a general working knowledge of their operation. The book contains 32 chapters including one on Shipyard Repairs, and a revised chapter on Obtaining a License as a Motorship Engineer.

2—Manual of A.S.T.M. Standards on Refractory Materials

210 pages   6 × 9   Price $1.50

This latest compilation of all A.S.T.M. Standards on Refractory Materials is the fifth sponsored by A.S.T.M. Committee C-8 on Refractories. It includes new standards for air setting refractory mortars, fireclay plastic refractories both for boiler and incinerator services, methods of test for measuring the shrinkage, spalling and workability index of fireclay plastic refractories, and a method for measuring the thermal conductivity of insulating fire brick.

Seven specifications on refractories for various types of service are given in the book. There are two classifications of materials and the remaining 16 standards give various methods of testing for fireclay refractory brick, fireclay plastic refractories, insulating fire brick and for various types of refractory materials.

An important part of the book is the section giving ten industrial surveys of refractory service conditions covering: Open-Hearth Practice; Electric Furnaces Used in Steel Manufacture; Malleable Iron Industry; Copper Industry; Lead Industry; By-Product Coke Ovens; Lime Burning Industry; Glass Industry; Portland Cement Industry; and Stationary Steam Boilers.

3—Technical Dictionary

957 pages   Price $5.00

An important feature of this dictionary, recently compiled by British editors, is the inclusion of both the English and American terminologies where these differ from one another. Special care has been taken to do this, and leading American authorities have been consulted. Here you can find, in an instant, exact definitions of many terms you may wish to know, scientific words that are new to you, or recently coined technical terms.

The reference contains hundreds of words not found in ordinary dictionaries. It will be useful both to the specialist who wants to be familiar with terms in other fields, and to the layman who wants to know the terms used most frequently in science, engineering and industry. It meets the demand for up-to-date information as no other reference does.

It is reported to be the most comprehensive technical reference in English, with more than 50,000 entries, covering in one compact volume all branches of modern science and industry.

4—Plant Protection

By E. A. Schurman

148 pages   5 × 7$^{1}/_{4}$ Price $2.00

Industrial plant protection has become a specialized branch of modern police science. The essence of the work is prevention rather than investigation of crimes already committed, and the recognized menace of spies, saboteurs and fifth columnists compels established or newly organized police departments to adopt new methods ensuring more adequate security.

The author, E. A. Schurman, Chief of the Protection Department of the Glenn L. Martin Company, is a recognized authority on this subject, and in this book nothing has been recommended which has not survived practical application by organizations whose efficiency of operation is widely known.

5—How to Read Electrical Blueprints

By Gilbert M. Haine and Carl N. Dunlap

318 pages   5$^{1}/_{2}$ × 8$^{1}/_{4}$ Price $3.00

The electrical industry has many branches and, because of the diversified nature of the work performed and the equipment used, each branch uses a type of blueprint and certain symbols designed to meet its own particular needs. For this reason, and to avoid confusion in the mind of the reader, the text of this book is divided in sections, eight of which deal with different branches of the electrical industry.

Following a brief section on the making of blueprints and the principles involved in laying out a drawing, the reader is introduced to the subject—How to read architectural blueprints; and in the sections that follow: How to read: diagrams for bell and signal wiring; house wiring blueprints; administration building blueprints; automobile wiring diagrams; diagrams of generators and motors; symbols for control diagrams; motor control diagrams; and power station blueprints. Each section is supplemented with an informative list of questions and answers and a set of "quiz" questions designed to test the reader's knowledge of the subject discussed. The book is admirably illustrated with many line cuts and halftones and, where symbols are presented, each symbol is accompanied by a pictorial sketch of the object or equipment indicated. The book also contains a comprehensive 12-page index and a set of nine instructive blueprints in a back cover pocket.

6—Marine Electric Power

By Captain Q. B. Newman

238 pages   4$^{3}/_{4}$ × 7$^{3}/_{8}$ Price $2.50

This book explains the essential principles of electrical engineering to the layman or high school student without recourse to a knowledge of advanced mathematics and physics. It is written in an easy conversational style and covers the more elementary aspects of electrical equipment and operation. The text includes 28 chapters which are illustrated with 160 diagrams and charts.

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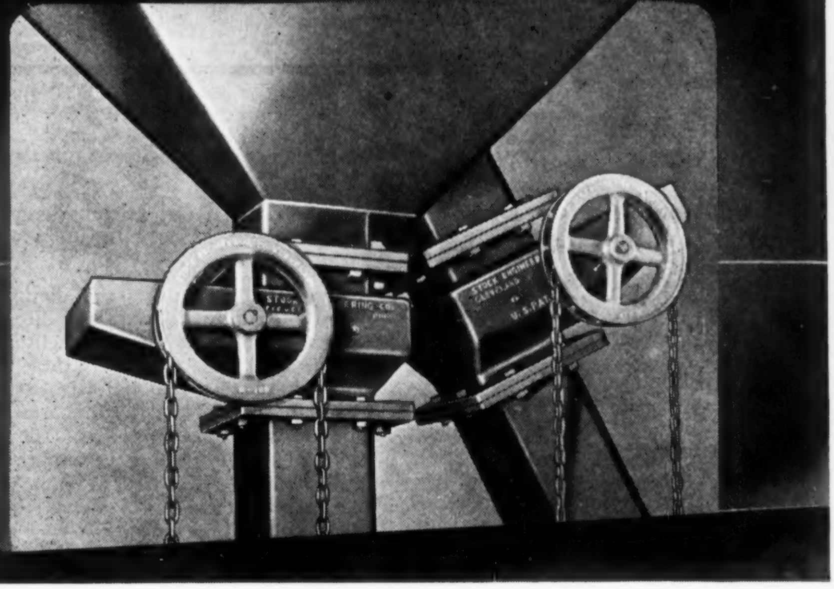

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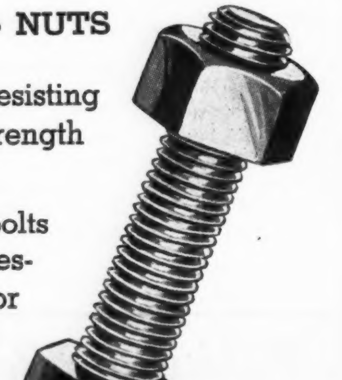

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